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Central Eurasia: Space

DEVELOPMENT OF SOVIET SPACECRAFT FOR MANNED MISSIONS

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[I. B. Afanasyev; NOVOYE V ZHIZNI, NAUKE, TEKHNIKE: SERIYA KOSMONAVTIKA, ASTRONOMIYA, No 12, Dec 91]

[Text]

Annotation

In this monograph, a number of designs involving manned spacecraft developed in the Soviet Union in 1960-1980 are described for the first time ever.

The monograph is intended for a wide circle of readers.

Introduction

Just five years ago, this monograph could not have appeared. But now, after the declaration of glasnost and openness, and especially after the reinforcement of those concepts by the publication of once classified documents and memoirs of eyewitnesses, this writer feels confident that this story can and must be told. The main impetus behind his coming out with this monograph was the appearance in the press of various articles that incorrectly interpreted, and often purposely distorted, the facts associated with the past and the present of our country's space program—something that leads to criticism of "Soviet space" by people quite far removed from the day-to-day affairs of the space program. One reason for such a state of affairs may very well be the absence of factual, accurate information on that area.

Now, and especially in the near future, many Soviet space programs are at risk of remaining completely obscure to the general public. A sad lesson confirming those words will forever be our lunar program, the mandatory secrecy of which resulted in our space program—and with it, all of our science—being deprived of the prospects of a natural course of development and taking the dead-end road of directly copying foreign equipment with all its infrastructure. However, it looks as if the leadership of the sector and of the country as a whole didn't learn anything from that then and hasn't learned anything from it now. Since no gains other than political gains were expected from the program, they brushed it aside, announcing to the entire world that we didn't have such a program. In addition, the stock of completed research was almost completely destroyed: several flight models of the N1 launch vehicle were disassembled, the "lunar detachment" of cosmonauts was disbanded, lunar craft fell apart in museums and scientific research institutes that were closed to the public, and all the research projects that were associated with that area and that promised in the near future good scientific-technical results were shut down. Finally, as a result of someone's stupid order, most of the scientific-technical design documentation was destroyed. Now fragments of the lunar program exist only in the heads and the workbooks of the remaining advocates.

Almost the very same thing can be said of other projects that were taken to various levels of development but, for one reason or other, never saw the light of day. The lack of coordination among the enterprises of the space sector, their secrecy, and the virtually complete absence of reliable information that results from the work not being appraised widely enough lead to the duplication of various efforts at various levels by the enterprises. With that, the very same mistakes are made, mistakes that could have been easily avoided if comprehensive information about the efforts had been available. But we write everything off as the mythical "state" secret, and now it's the "trade" secret. We won't talk about certain technological secrets—but they do, of course, exist. But for all that, if we did have such "secrets," we wouldn't be behind the West in a field like space, in which historically we've enjoyed such preeminence.

This writer has tried not to place emphasis on any political assessment of the value of the programs represented in the monograph or on the effects that certain events had on the fate of those programs. The primary aim of the monograph is to discuss the manned spacecraft designs that were developed in the USSR in 1960-1980 and were not disclosed to the general mass of readers; it elaborates as briefly and as concisely as possible the features of the design of the individual vehicles. In addition, the monograph will discuss the course of the programs and clarify points of information about the little-known vehicles that were referred to in the press. The discussion of the designs associated with the vehicles is presented in a chronological order that is based on the beginning of the programs.

This writer is grateful to the veterans of the Salyut Design Bureau, the Khimmash Design Bureau, the Trud Design and Scientific Production Association, the N. E. Bauman Moscow State Technical University, the Molniya NPO [scientific production association], the Energiya NPO, the Energomash NPO, the Central Aerohydrodynamics Institute, and the Mashinostroyeniye Central Design Bureau for their help in selecting and analyzing the materials for the monograph.

Glide Spacecraft Project (OKB-256)

At the same time that the Air Force and NASA in the United States began developing a design of the Dyna-Soar boost-glide vehicle, aviation design bureaus in the USSR—P. V. Tsybin's OKB-256 and V. M. Myasishchev's OKB-23—were studying designs of piloted winged vehicles. [*We intend to familiarize our readers with the history and the fate of that design under the heading "The Pages of History" next year—Editor*]

The preliminary design of a glide spacecraft (GS) for deorbit and landing on the Earth was developed in OKB-256 at the request of S. P. Korolev and was approved by P. V. Tsybin on 17 May 1959.

According to the design, the GS, carrying a cosmonaut, was to be placed into the circular orbit of an artificial Earth satellite with an altitude of 300 km by the Vostok launch vehicle (LV). After an orbital flight of 24-27 hours, the GS was to leave orbit and return to Earth, gliding through the dense layers of the atmosphere. In the early part of the reentry, in the zone of intense

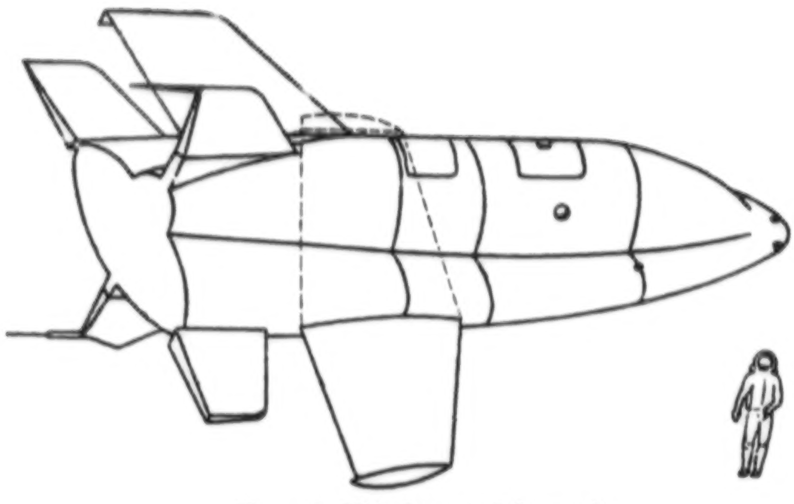


Figure 1. Glide Spacecraft Lapotok

thermal heating, the GS was to make use of the lift of its uniquely shaped fuselage (Fig. 1)—S. P. Korolev gave it the name Lapotok [Sandal]—and then, after dropping to a speed of 500-600 m/s, it would glide from an altitude of 20 km with its swing-out wings, which had initially been "folded behind its back." Control of the GS in flight would be effected with jet nozzles and aerodynamic control surfaces.

GS descent from an artificial Earth satellite orbit would take one and a half hours. The landing was to be done on a specially designed landing field on bicycle-type ski landing gear—the rear ski would touch down first, and then the front ski.

The GS fuselage had a steel skin welded to the structural frame. A metal, bottom shield mounted so that there was a gap of 100 mm protected the fuselage from heating. The nose of the fuselage and the leading edges of the aerodynamic surfaces, which were made of steel, were to be cooled, and the possibility of using liquid lithium for that was under study. According to calculations, the maximum temperature of the front part of the shield and the leading edges of the control surfaces could reach 1200°C, as opposed to the upper part of the fuselage, where the expected temperature would not exceed 400°C. The folded steel swing sections of the wings, located in the aerodynamic "shadow" of the fuselage when the GS was gliding with an angle of attack of 55-60°, would not be subjected to a great deal of heating in the zone of maximum thermal fluxes at hypersonic speeds.

Inside the fuselage were a pressurized cabin for the cosmonaut and a pressurized instrument compartment, both made of aluminum alloy and protected by thermal insulation. Facing an instrument panel, the cosmonaut sat in an ejection seat that had three positions—launch, working, and rest. The cabin had a life-support system, two side viewports, and an astrotracker.

In the instrument compartment, right inside the fuselage, was equipment necessary for orbital flight and reentry. For orbital maneuvers, the GS had a suspended propulsion system adjacent to the bottom panel of the fuselage and enclosed by a fairing. The propulsion system included fuel tanks, a fuel-feed system, and two liquid-fuel rocket engines (LFREs)—a braking engine and a vernier engine. The propulsion system was to be separated from the GS at an altitude of 90 km, after the braking impulse for deorbit had taken place. The attitude of the GS in orbit and during entry into the dense layers of the atmosphere would be controlled by jet nozzles that operated on products of the decomposition of hydrogen peroxide. After that, aerodynamic surfaces would be used.

In the event of an LV failure at altitudes of 10 km or lower, the cosmonaut could eject from the GS cabin. At higher altitudes, the GS would make an emergency separation from the LV, the swing sections of the wings would unfold, and the vehicle would descend to the ground.

Korolev was well posted on all the work being done on the GS in OKB-256. Space-vehicle and LV designers from his OKB participated in the work. In addition, the very large groups from the Central Aerohydrodynamic Institute and the All-Union Institute of Aviation Materials were involved in the work.

After work on the GS got under way at the Central Aerohydrodynamic Institute, it turned out that the problems that were coming up for the the winged-space-vehicle developers were much more serious that anyone had anticipated. Specifically, it didn't become clear until after wind tunnel tests that the thermal loads on the thermal-protection shield would be considerably greater than the calculated loads and that the material of the shield would have to be changed. It also became clear that on the most intense leg of the descent, the hinge unit for the swing section of the wing was in a "dead zone"

that had an elevated influx of heat and practically no heat removal at all. The design had to be studied in greater detail, with modeling of actual flight conditions on prototype vehicles.

As we know, for the first spacecraft, the Vostok, Korolev chose a configuration with a ballistic reentry vehicle because it was a simpler, reliable configuration that required the least expense in the experimental development phase. In addition, the campaign that got under way at that time in favor of rockets, as opposed to military aircraft, affected many aviation design bureaus. OKB-256 was shut down in 1960. Chief Designer P. V. Tsybin went to work as Korolev's deputy in OKB-1, where he made a large contribution to the engineering and development of updated Vostoks, new Soyuzes, and the Soyuz T, as well as unmanned interplanetary probes and the Molniya communications satellite. By agreement, the materials pertaining to the GS were transferred by Korolev to A. I. Mikoyan's OKB, where work then got under way on the Spiral aerospace system.

Heavy Interplanetary Spacecraft Project (OKB-1)

The heavy interplanetary spacecraft (HIS) design could have been one of the most promising, effective space designs developed in the USSR, one that would not have been very expensive to execute.

But before discussing the HIS, we need to go back to a time prior to the design, which went hand in hand with the development of the N1 launch vehicles from the very beginning.

The primary job of the rocket [N1] (whose development is discussed in detail in the monograph by Academician V. P. Mishin, *Why Didn't We Get to the Moon?*) was to be the placement heavy satellites into near-Earth orbit. The specifications for the design of the LV stipulated that the launch mass of the booster could not exceed 2200 tons, with the mass of the payload that was to be placed into low near-Earth orbit at 75 tons. Based on the design stipulations, the N1 rocket was optimized specifically for those initial characteristics. The ground structures and all the infrastructure were developed for such a rocket. And although the rocket under development was striking in its size, the design never evoked any particular questions to which, during the design, one could give a strictly negative response. For example, there was no extreme skepticism on the part of opponents.

The N1 rocket can safely be called the principal brainchild and dream of S. P. Korolev. Sergey Pavlovich had long been pondering its development, even before the space age began. On the preliminary design submitted in July 1962, there was a notation made with Sergey Pavlovich's hand: "We were thinking about this in 1956-57." He understood that once such a powerful launch vehicle was put on line, broad horizons would open up for the Soviet space program. One of the urgent tasks of the new booster would involve the launches of heavy unmanned probes and manned spacecraft to the planets of the solar system.

In OKB-1, the design section headed by M. K. Tikhonravov was studying various versions of spacecraft for a flight to Mars. The research was done at first in an enterprising manner by groups of designers led by G. Yu. Maksimov and K. P. Feoktistov during their free time.

The design produced by the Maksimov group was aimed at a rapid realization of the program with the resources at hand. It presumed the creation of a relatively simply designed, small-mass spacecraft with a three-man crew. The design allowed for a flyby of Mars, with the research done on the flyby trajectory, with no landing on the surface and no entry into near-Mars space, and with a subsequent return of the spacecraft to the vicinity of Earth. With an adjustment of the flight trajectory, the spacecraft could be sent very accurately toward Earth, where the reentry vehicle would separate from the spacecraft, would enter the atmosphere at a velocity exceeding planet escape velocity, and would perform a controlled descent and a parachute-assisted landing.

In terms of its design, that version of the HIS consisted of a cylindrical crew cabin with an instrument-equipment bay, a propulsion system for trajectory adjustment, and solar panels on the exterior of the craft. Not having the proper initial data on the reliability of the huge N1 launch vehicle, the designers made provisions for two profiles in which the interplanetary spacecraft would be put into near-Earth orbit: one with cosmonauts on board, and one with a later "placement" of the crew on the interplanetary spacecraft. In the latter case, an unmanned interplanetary spacecraft with an upper stage would be placed into orbit by the N1, and the crew would be delivered to that craft in one of the spacecraft being developed at that time by OKB-1. After the cosmonauts had been transferred, the HIS with its upper stage would leave orbit and set out for Mars.

The design produced by Feoktistov's group was based on a more complex, multilaunch profile, with assembly of the HIS in near-Earth orbit and its subsequent launch to Mars. For a propulsion system, the complex would use highly efficient, electric rocket engines that would get their energy from a nuclear power plant. Because of the low thrust of the electric rocket engines, the boost of the spacecraft in a spiral for gathering momentum would take several months. In general appearance, this HIS resembled a daisy, with the nuclear power plant in the center and the radiator-emitters serving as the petals. At the far end of the "flower stem" was the crew cabin. The designers devoted a great deal of attention to the engineering aspect of the design—primarily to the development of the nuclear power plant and the electric rocket engines.

In discussing the design of the HIS, one must not forget that it got under way in the very early 1960s. The design had no counterparts, and could not have had any. As a

result of that, the designers were faced with a multitude of very complex problems whose solution, even at the current level of science and technology, would require very serious efforts. But the highest level of enthusiasm, totally unfettered imagination, and a belief in their own capabilities and in those of domestic science and technology helped the developers overcome the difficulties that cropped up along the way.

Based on the known flight trajectory for the spacecraft, including a return to the vicinity of Earth, all of which would take more than a year, a great deal of the designers' attention was riveted on the life-support system for the spacecraft's crew. The existing life-support systems—which were based on the use of unrenewable reserves of oxygen, water, and food—would not enable the execution of the flight program because they involved too much mass. In that context, a life-support system with a so-called closed loop could be used. Understanding the complexity of producing closed-loop life-support that used physicochemical processes, the designers placed their hopes primarily on biological systems that consisted of a simplified replication of the closed ecological system of Earth. Of course, it would difficult to set up the full cycle of matter in the somewhat small space of a spacecraft, but "closing" a system for such vitally important components as water and oxygen would be possible.

Drinking water would be produced primarily from the moisture breathed out into the cabin atmosphere by the cosmonauts and then purified by ion-exchange resins. Some of the drinking water and some of the water for engineering needs could be recovered from human fluid wastes by means of various physicochemical and biological processes.

For regenerating oxygen from the carbon dioxide produced by the cosmonauts, containers with chlorella-type algae would have to be used. In addition, those algae could also partially treat other human waste.

Food would be kept in freeze-dried form and would be very carefully chosen before the flight on the basis of the criteria of food value and specific mass. The food rations on the spacecraft would have to be supplemented by vegetables matured in an onboard hydroponic greenhouse, which would make it possible to economize in terms of food mass by 20-50 percent. Since the greenhouse would be a component part of the HIS, delivering sunlight to the plants was a serious problem. The task was handled brilliantly through the use of large external solar collectors.

A model of the HIS living quarters was built—an experimental ground complex in which experimenters G. Manovtsev, V. Ulybyshev, and A. Bozhko spent a year—in order to perfect the elements and units of the closed-loop life-support system on Earth and to address the psychological problems associated with a crew's lengthy stay in the enclosed space of a spacecraft and a diminished volume of information received from the outside.

[The year-long Soviet experiment involving operational tests of the closed-loop life-support system began 5 November 1967. Similar tests, 90 days long, involving a four-man crew were conducted in the United States considerably later, in July-September 1970.]

Another problem that was associated with a lengthy space flight involved protection of the crew from solar flares and galactic background radiation. Calculations and satellite experiments made it possible to compute a total cumulative dose of irradiation received by the cosmonauts that physicians deemed would be acceptable. Cosmonauts could be safe from radiation during periods of solar flares by staying in a radiation shelter that would be build in the form of a passage in the instrument-equipment bay. In the shelter, the cosmonauts, surrounded on all sides by instruments, could outwait a solar flare, controlling the spacecraft from a simplified console.

The workload of the cosmonauts in controlling the spacecraft would be reduced as much as possible by transferring it to automatic units that would deliver information on the operation of the spacecraft systems to the control console in the form of three values: "Normal," "Not Normal," and "Failure." The cosmonauts would be able to perform inflight repair of the spacecraft's radio-and-electronic equipment, which was to be constructed in the form of easy-access consoles and removable circuit cards.

One question that, to the very end, remained unclear to the project's participants involved the almost complete absence of knowledge of the effects of long-term weightlessness on the human body during space flight. Initially, it was suggested that artificial gravity be created aboard the spacecraft by rotating individual parts of the HIS about its axis, but the relatively small size of the centrifuge led to the appearance of Coriolis accelerations that distorted human perception of gravity and that were harmful to the body.

Korolev found the work done by the groups of enthusiasts to be quite interesting. On the basis of his initiative, a special design section was set up for the HIS.

The development of the first design version of the HIS demonstrated the advisability of creating an experimental ground complex, which was later created. The work on the second version went a little farther and culminated in 1969 with the release of an experimental design.

It was decided in the early 1970s to create orbital stations in order to learn whether man could stay aloft in space for lengthy periods without artificial gravity. The priority given first to the lunar program and then to the orbital stations slowed the development of the HIS. Of course, we didn't need to hurry with the lunar program. Rather, we needed to gradually perfect the N1, which would make it possible to create a heavy orbital station and, as a result, the HIS and perform one of the most grandiose, impressive missions of the 20th century, one

that would be entirely comparable to and, in some ways, would exceed the landing on the Moon. The most important thing was for our space program to travel its own path and for there not to be a "Moon race" with the United States. Moreover, once we had garnered experience in the creation of the HIS, nothing would keep us from undertaking full-scale development of a lunar or Mars mission. From today's point of vantage, a flyby of Mars would have been no less prestigious, and performing it might have been simpler. But at the time, replacing the lunar program with a Mars program was very difficult in psychological terms, because many felt that, in light of our "shining victories in space, we were just about to "conquer" the Moon. The shutdown of operations in one of the key elements of the HIS—the N1 rocket—resulted in the program's being quickly closed down.

Work in the Soyuz Program (OKB-1)

Understanding that the increasing complexity of the tasks facing the domestic space program would, with time, require a dramatic increase in the mass of spacecraft for flights in artificial Earth satellite orbits and to other planets, S. P. Korolev and his colleagues devoted a great deal of attention not only to the development of the N1 design, but also to the question of the assembly of vehicles in artificial Earth satellite orbit. As early as 10 March 1962, Korolev approved a technical prospectus titled "Complex for the Assembly of Space Vehicles in Artificial Earth Satellite Orbit (the Soyuz)." That document was the first to provide a corroboration of the possibility of using a modified Vostok-7 spacecraft with a "cosmonaut/assembler" aboard to perfect in-orbit docking and assembly. The spacecraft would be equipped with approach and docking systems, as well as with a main propulsion system that could be fired many times and a system of vernier engines for docking and attitude control. The Vostok-7 spacecraft could be used for assembly in artificial Earth satellite orbit of a space rocket (Fig. 2) consisting of three identical rocket stages. Such a space rocket was to be for the circumlunar flight by the L1 special-purpose spacecraft carrying a crew of one-three people.

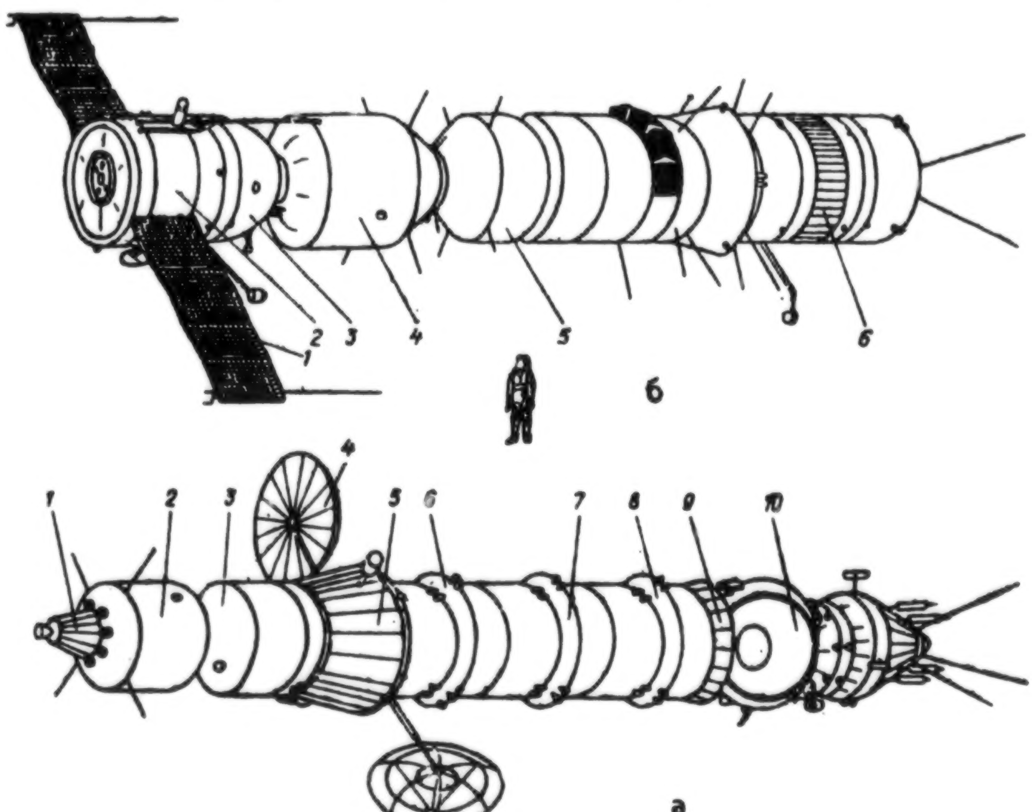


Figure 2. Complex for assembly of space vehicles in artificial Earth satellite orbit proposed for the Soyuz program in 1962 (lower illustration): 1—Nose propulsion system of L1 spacecraft; 2—Living compartment; 3—Reentry vehicle; 4—Solar panel; 5—Equipment bay; 6, 7, 8—Rocket stages; 9—Jettisonable section of lower rocket stage; 10—Vostok-7 spacecraft
Complex proposed in 1963 (upper illustration): 1—Solar panel; 2—Instrument-equipment bay of Soyuz spacecraft; 3—Reentry vehicle; 4—Living/working quarters; 5—Upper rocket stage; 6—One of the spacecraft/tankers

According to the prospectus, the L1 spacecraft had a unique configuration consisting of two fine-adjustment propulsion systems (one fore and one aft), living quarters, a reentry vehicle, and an equipment bay, which was attached to the Vostok-7 spacecraft by the three rocket stages. In the spacecraft's mission profile, one could clearly trace the need for the use of a specially shaped reentry vehicle with a lift-drag ratio, which would make it possible for the vehicle to perform a maneuver in the atmosphere that would reduce the g-loads on the crew and to control the descent trajectory of the reentry vehicle. That maneuver dramatically narrowed the zone for the spread of points for vehicle touchdown. The possibility emerged for making a landing after the flyby of the Moon in a designated area of the Soviet Union.

That same prospectus suggested the use of docking to create an orbital station manned by three people, intended for observing the Earth, and consisting of three units: a living unit, a science-package unit, and a crew-delivery spacecraft. See graphic below.

The spacecraft was to be the Sever, whose design was being studied at that time by OKB-1. That vehicle was something of a transition stage between the Vostok spacecraft and the spacecraft of the next generation, which later received the name Soyuz. The Sever consisted of a new-shaped reentry vehicle with lift-drag ratio and an equipment bay.

The prospectus substantiated the possibility of launching a communications satellite into geostationary orbit with a rocket assembled from separate rocket stages. The stages of the vehicles in all those versions would have to be placed in orbit by a Soyuz launch vehicle.

After a certain period of time, a second prospectus appeared. It was titled "Assembly of Space Vehicles in Earth Satellite Orbit" and was approved by Korolev on 10 May 1963. In it, the Soyuz program resounded clearly and persuasively. The principal focus of the document was a complex consisting of successively launched components—an upper rocket stage, spacecraft/tankers for fueling the upper stage, and the Soyuz spacecraft—all of which would be docked in orbit. After the upper stage tanks were filled with the fuel delivered by the "tankers," the liquid-fuel rocket engine (LFRE) stage would be started and the Soyuz would be accelerated to its flyby of the Moon. Docked to the upper stage, the Soyuz—consisting of living/working quarters with a docking port, a reentry vehicle, and an instrument-equipment bay—would be boosted "rear end first." In flight, the Soyuz propulsion system would be used for trajectory adjustment. After the circumlunar flight, upon return to Earth, the sections of the spacecraft would separate, and the reentry vehicle would perform a controlled descent and landing in a designated region of the Soviet Union. In the prospectus, the Soyuz already had a shape similar to what it is now.

The prospectus presented two main objectives: to perfect in-orbit docking and assembly, and to perform a flyby of the Moon with a manned vehicle. In Korolev's opinion, linking the designs associated with those two objectives gave preeminence to the USSR in the exploration of space. Work in the Soyuz program was given the green light.

In the context of the development of a version of a direct flyby of the Moon by the L1 spacecraft, the Soyuz program aimed at perfecting approach and docking, with subsequent transfer of crew members from one spacecraft to another. The preliminary design of the Soyuz, signed in 1965, reflected what were already new specifications and performance requirements for the spacecraft. Debugging of the Soyuz in unmanned mode got under way on 28 November 1966 with the launch of the Cosmos-133 satellite. After an unsuccessful launch of an unmanned Soyuz in December 1966—an attempt that ended with a launch-vehicle failure and the triggering of the emergency rescue system on the launch pad—an orbital flight was performed on 7 February 1967 by a second unmanned Soyuz spacecraft (Cosmos-140), with a landing in the Aral Sea.

The first manned flight, aboard the Soyuz-1, was performed on 23-24 April 1967 by pilot-cosmonaut V. M. Komarov. Because of a failure of the parachute systems during descent, however, the flight ended in disaster. The first automatic docking was performed on 30 September 1967 by the unmanned spacecraft/satellites Cosmos-186 and Cosmos-187, and it was followed by another docking on 15 April 1968, between Cosmos-212 and Cosmos-213. After an unmanned flight of a Soyuz launched on 28 August 1968 (the Cosmos-238), regular flights of the Soyuzes got under way. The objective of the Soyuz program—the docking of manned spacecraft and the extravehicular transfer of cosmonauts—was actually

achieved on 16 January 1969 during the flight of the Soyuz-4 and Soyuz-5 spacecraft, which carried cosmonauts V. A. Shatalov, B. V. Volynov, A. S. Yeliseyev, and Ye. V. Khrunov. The remaining Soyuz spacecraft were re-assigned for the performance of engineering experiments in a group flight (Soyuz-6, -7, and -8, with cosmonauts G. S. Shonin, V. N. Kubasov, A. V. Filipchenko, V. N. Volkov, V. V. Gorbatko, V. A. Shatalov, and A. S. Yeliseyev) and in a long-duration flight (Soyuz-9, with cosmonauts A. G. Nikolayev and V. I. Sevastyanov, launched 1 June 1970), which lasted 17.7 days. Two last Soyuz spacecraft, on which the approach system was to be perfected for the L3 lunar complex, were never used for that.

Spiral Project (OKB-155)

In the early 1960s, OKB-155 of the State Committee for Aviation Equipment, headed by A. I. Mikoyan, began research on multiple-unit aero-space systems that combined the features of airplanes and rockets. In 1965, a plan was authorized for operations in the Spiral program and an experimental design of the system was made. Deputy Chief Designer G. Ye. Lozino-Lozinskiy was named head of the program.

The main purpose of the Spiral program was to create a manned orbital airplane for performing special jobs in space and for ensuring the possibility of regular, safe transfers between Earth and orbit. Launching the orbital airplane into space called for the creation of an airborne-orbital system (Fig. 3) consisting of a reusable hypersonic booster-airplane and an expendable two-stage booster rocket.

Two versions of the booster-airplane were studied, each with four multimode turbojet engines that operated either on liquid hydrogen (the more promising version) or on kerosene (the more conservative version). For launch from a runway, the booster-airplane used a launch truck, and either the *M-6* (for the first version) or the *M-4* (for the second version) was used to boost the system to hypersonic Mach speed. Separation of the stages was to take place at altitudes of 28-30 km and 22-24 km, respectively. After that, an LFRE-powered booster would be put to use, and the booster-airplane would return to the launch site.

The booster-airplane was a relatively large airplane built along the lines of a "flying wing," highly sweptback with vertical stabilizer surfaces on the wing tips. The turbojet unit was under the fuselage and had a common, regulated supersonic air-intake. In the upper part of the hypersonic booster-airplane, fixed to a pylon was the orbital aircraft with a rocket booster, the fore and aft ends of which were enclosed in fairings.

The orbital aircraft was designed with an airframe triangular in plan and was considerably smaller than the booster-airplane. It had sweptback swing sections of wing that were in a vertical position during the injection phase and the initial reentry phase and were folded out during

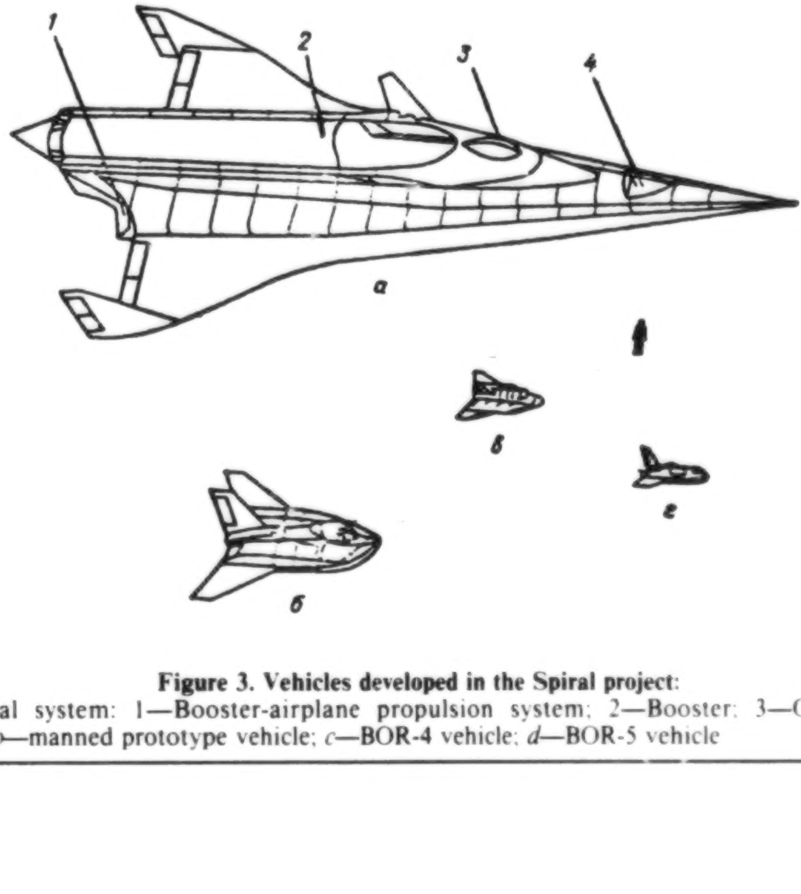


Figure 3. Vehicles developed in the Spiral project:
a—airborne-orbital system: 1—Booster-airplane propulsion system; 2—Booster; 3—Orbital aircraft; 4—Booster-airplane; *b*—manned prototype vehicle; *c*—BOR-4 vehicle; *d*—BOR-5 vehicle

gliding, thereby enlarging the lifting area. A booster would be used to place the orbital aircraft into a low, near-Earth orbit roughly 130 in altitude, and the orbital aircraft would complete two or three orbits. It would be able to perform maneuvers to change inclination of the plane of orbit and orbital altitude. After performing its flight, the orbital aircraft would enter the atmosphere, drop to hypersonic speed at a large angle of attack, with a capability for a large lateral maneuver, and then, after reducing speed, fold out its wing, glide, and land at any airfield. The airframe of the orbital aircraft would be protected from heating during reentry by a metal shield installed on its underside on articulated mounts; the shield performed several structural functions. During reentry, the folded swing sections would be in the aerodynamic "shadow" of the fuselage.

Injection of the orbital aircraft into orbit after separation from the hypersonic booster-airplane would be effected by a booster that consisted of a two-stage rocket with oxygen-hydrogen or oxygen-kerosene LFREs.

For in-orbit maneuvering, the orbiter would use a main LFRE, as well as two emergency LFREs. Vernier engines with an independent feed system would be used for orientation and control. The orbiter would operate on nitrogen tetroxide/unsymmetrical dimethylhydrazine. Maneuvering of the aircraft during the final segment of the glide (approach to the runway and second-pass approach in the event of an inability to land on the first approach) would be powered with a turbojet engine operating on kerosene. The landing would be done on ski landing-gear.

One of the distinctive features of the orbiter was the onboard computer for navigation and automatic flight control.

Under study was the possibility of emergency rescue of the orbiter pilot on any segment of flight via the headlight-shaped cabin-capsule, which had a mechanism for ejection from the orbiter, a parachute, braking engines for reentry (in the event that the entire aircraft could not return to Earth from orbit), and a navigation unit.

An experimental, reusable single-seater orbital aircraft was designed for full-scale testing of the structure and main systems of the orbiter. It was built with a similar configuration, was somewhat smaller and lighter, and would be put into orbit by the Soyuz launch vehicle.

For testing the configuration of the orbiter in the atmospheric segments of the flight were prototype aircraft equipped with turbojet engines and launched from the Tu-95 carrier-aircraft. One of the prototypes would perform flights at subsonic speeds, the other, at speeds of Mach 6-8.

The main distinctive feature of the Spiral system was the large relative mass of the payload, which was two-three times greater than the relative mass of the payloads of ordinary expendable launch vehicles. The cost of launching the payload, however, would be lower by a factor of 3-3.5. In addition, the system's advantages included the possibility of selecting a wide range of launch directions, maneuvering in space, and an airplane landing in complex weather conditions.

The Spiral project envisaged a broad range of operations. According to the plans, the development of the subsonic prototype aircraft was to get under way in 1967; the development of the hypersonic prototype, in 1968. The first experimental vehicle was to be sent into orbit in 1970, in unmanned mode. The first manned flight was slated for 1977. Work on the hypersonic booster-airplane was to begin in 1970. If a decision was made to develop the hydrogen-powered booster-airplane, the development of it was scheduled to get under way in 1972. Flights of the fully outfitted Spiral system could begin in the mid-1970s.

For the study of the stability and controllability of the orbital aircraft on various segments of the flight and for evaluation of the thermal protection, flying 1:3 and 1:2 scale models of the vehicle were built. They were called "unmanned orbital boost-glide vehicles" (abbreviated in Russian, BOR), and the swing sections of their wings were fixed. The wide-ranging program of tests of the vehicles included wind-tunnel tests at the Central Aerohydrodynamics Institute and bench tests that simulated various regimes and stages of flight. Then began the flight [broskovyye] tests, in which rockets were used to put the BOR vehicles into a ballistic flight trajectory simulating reentry and landing.

Despite the clear technical and economic corroboration, the leadership of the country evinced no interest in the Spiral, and that had a negative effect on the program dates, which stretched out over many years. Eventually, the Spiral program was reoriented toward flight tests of prototype vehicles, with no prospects for the actual development a system on their basis. In 1976, with the beginning of work in the Energiya-Buran program, the fate of the Spiral was sealed once and for all.

But the tests of the prototype vehicles developed in the Spiral program continued. A manned prototype airplane was ready for subsonic flight in the mid-1970s. Its flights tests began with short hops in May 1976: the prototype airplane took off from a runway under the power of its own turbojet engine and then landed immediately. Test pilots A. Fastovets, I. Volk, V. Menitskiy, and A. Fedotov took part in those flights. On 11 October 1976, the vehicle made a flight from one airfield to another airfield.

In 1977, tests of the prototype vehicle got under way in which it was lifted to a given altitude by a Tu-95K carrier-aircraft—initially, the airplane was not released. On 27 October 1977, the first air launch of the vehicle from the carrier-aircraft was performed; A. Fastovets piloted the vehicle. Five more flights of the prototype to subsonic speed were performed in 1978. The completion of the flight tests of the prototype in September 1978 marked the end of the Spiral program.

To perfect the designs underlying the concept of the reusable Buran orbiter, it was decided that the research results achieved in the Spiral program should be used. For that, the BOR vehicles were used, after substantial modification. They were outfitted with a new thermal protection system similar in its characteristics to that of Buran and with a jettisonable braking propulsion system for reentry. The systems of the boost-glide airplane, because of its extremely small size, were simplified as much as possible. The flight after reentry would be a glide, with subsequent descent by parachute to water.

On 3 June 1982, when the development of the Buran orbital craft was nearing its culmination, the BOR-4, under the name Cosmos-1374, was launched from Kapustin Yar atop a Cosmos launch vehicle, to test the thermal protection materials of the craft. After making 1-1/4 orbits, the boost-glide vehicle made its reentry, with a lateral maneuver spanning 600 km; it flew farther and splashed down 560 km from the archipelago of the Keeling Islands in the Indian Ocean, where seven rescue ships on duty there pulled the BOR-4 out of the water. The rescue operations were filmed by an Australian Orion patrol plane that was in the area.

The second orbital flight of the BOR-4, under the name Cosmos-1445, took place on 15 March 1983. The boost-glide vehicle splashed down 556 km south of those same Keeling Islands and was rescued by Soviet ships. The third flight of the BOR-4 boost-glide vehicle (Cosmos-1517) was on 27 December 1983. This time, instead of the Indian Ocean the Black Sea was chosen as the splashdown site. The tracking ships noted the firing of the braking engine of the vehicle when the vehicle was over the North Atlantic.

On 4 July 1983, the first model of the Buran orbiter, in a smaller scale (BOR-5, or B-5), was launched to confirm the actual configuration of the craft. The all-metal miniature orbiter, equipped with sensors and recording gear, made a suborbital flight from the Kapustin Yar cosmodrome. After that, five more suborbital flights of the B-5 vehicle were made.

The last launch of the BOR-4 boost-glide vehicle was on 19 December 1984, under the name Cosmos-1614. As in the previous launch, the BOR-4 splashed down in Black Sea after circling the Earth once.

LK-1 Spacecraft Project for Circumlunar Flight (OKB-52)

In 1960, V. N. Chelomey's OKB, which was part of the State Committee for Aviation Technology, began work on the development of rocket-space systems. By 1964, with the help of the State Committee enterprises and those of the defense industry, Chelomey's OKB had created the Polet maneuverable vehicles, the first of their kind in the world, and had developed the Proton research satellites and the launch vehicles for putting them into orbit—among them the powerful UR500K Proton rocket.

In addition to unmanned vehicles, the OKB was active in developing manned spacecraft called boost-glide vehicles and space gliders. Within the framework of such projects, the expectation was to create spacecraft that enabled man to go aloft in space and safely return to Earth. On 3 August 1964, in the midst of operations on the space gliders, Chelomey signed the experimental design of the LK-1 spacecraft, which would carry one cosmonaut on a flyby of the Moon in a looplike trajectory.

The LK-1 was to be launched by the powerful three-stage UR500K lanuch vehicle. Relying on the launcher's characteristics, the designers regarded the spacecraft as one that would consist of three units: a booster unit, an instrument-equipment unit, and a return module similar to the American Gemini spacecraft (located in the forward part of the spacecraft, it was enclosed by a fairing).

Rescue of the cosmonaut in the event of a launch-vehicle failure would be done by carrying the return module clear of the launcher by means of a solid-propellant emergency propulsion system affixed above the return module.

With a conical shape, the return module had some lift-drag ratio, which enabled it to perform controlled descent at planet escape velocity in the Earth's atmosphere, with acceptable g-loads and with a landing in a designated area of the Soviet Union.

Electrical power would be supplied to the spacecraft systems by solar panels, which would open after the spacecraft entered a translunar trajectory.

Noteworthy in the LK-1 design was the rather small mass and size of the return module. Gradually optimizing the characteristics of the systems of the spacecraft and the launcher, the designers managed to increase the return module's mass and make room for another cosmonaut. Work on the LK-1 was interrupted in late 1965 as a result of the orientation of the lunar program on the L1 spacecraft developed by OKB-1.

L1 Spacecraft for Circumlunar Flight (OKB-1)

On 15 December 1965, at a meeting of chief designers, S. P. Korolev presented an experimental design of the L1 spacecraft for a flyby of the Moon; Korolev had relied on research done earlier, in the Soyuz and N1 programs, and was familiar with the work done by Chelomey's OKB-52 on the UR500K launch vehicle and the LK-1 spacecraft. His design called for a flyby to be performed by a Soyuz spacecraft in a lighter version. The launch of the spacecraft from near-Earth orbit would be done by the D booster unit. The booster unit/spacecraft complex would be placed into low near-Earth orbit by the UR500K launch vehicle.

The advantage offered by Korolev's design over Chelomey's was that OKB-1 already had experience in developing and building the manned Vostok and

Voskhod vehicles and that the work in the Soyuz program, covering a broad front at that time, was going successfully. In addition, the decision to begin work on the L1 design was dictated to some extent by the fact that Korolev had a great deal of authority.

As with the LK-1 project, the L1 program called for a flyby of the Moon and a return to Earth by a spacecraft carrying a crew of two people. The short time frames given for realization of the program called for maximum use of the existing ground base, documentation, and materiel of the Soyuz program. The strict constraints imposed by the UR500K launcher and the D unit required that the mass of the L1 craft be 5.1-5.2 tons. For that reason, the designers were forced to lighten the Soyuz wherever they could, all the while striving to maintain the indices of its reliability. Specifically, they removed the living/working quarters from the spacecraft, some of the reentry vehicle systems (including the reserve parachute system), and some of the instrument-equipment compartment systems (one of four sections in every "wing" of the solar panels, and a backup LFRE in the approach/fine-adjustment propulsion system). In addition, substantial changes were made in the structure of the Soyuz to enable its use for the lunar flyby. The system for attitude control and control of motion was updated, as were the system for control of the onboard equipment complex and the system for radio communication with Earth; a directional antenna was installed. The number of jet nozzles controlling the motion of the reentry vehicle motion on the descent leg in the atmosphere was increased. The thermal-protection shield for the reentry vehicle was modified to withstand the heat during reentry at planet escape speed.

In the atmospheric leg of the injection, L1 would be enclosed in an aerodynamic fairing specially developed for that purpose. In the event of a launch-vehicle failure, the reentry vehicle would be carried clear by the emergency rescue system, which had a propulsion system more powerful than that of the emergency rescue system of the Soyuz spacecraft.

Since the living/working quarters of the Soyuz spacecraft were not present on the L1 vehicle, the reentry vehicle was secured against the fairing blocks at the moment of ignition of the propulsion system of the emergency rescue system by means of a special support cone attached to the upper part of the reentry vehicle. The cosmonauts entered the spacecraft on the launch pad through the hatch in the nose fairing, through the passage in the center of that special cone, and through the hatch to the reentry vehicle. In near-Earth orbit, the cone was jettisoned right before the ignition of the D unit.

The training of the cosmonauts in the L1 program began long before the first models of the spacecraft were ready. The training was done at first in ground models of the Soyuz reentry vehicle equipped with new control instruments, among which was the indicator field, which was being used for the first time. The cosmonauts remarked how easy it was to work with the new gear, but they also complained about how crowded it was in the reentry vehicle, in which they would have to spend seven days aloft.

The first launches of the L1 spacecraft were also to mark the beginning of tests of a new, three-stage version of the UR500 rocket, which had already launched f ir times (three of them successful) in a two-stage version. But it turned out that, from the very outset of its life, the UR500K launcher was tested not in a three-stage version, but in a four-stage version. The D unit, taken from the OKB-1-developed N1/L3 complex and partially filled with fuel, became the fourth stage of the new launch vehicle.

The first (mockup) model of the L1 spacecraft, which was designed for ground testing, was checked out as part of the UR500K-L1 complex at Baykonur in January 1967. The second model was launched into near-Earth orbit on 10 March 1967, under the name of Cosmos-146. That launch—in which the four-stage UR500K launcher with the D unit as the last stage was used for the first time ever—was meant to test the booster unit. The L1 went up in a simplified version. During the flight, the LFRE of the D unit was fired twice.

Subsequent work in the program was to consist of several launches of the L1 in unmanned mode, under the general name of Zond. Once two or three spacecraft had performed successful unmanı ed flybys of the Moon and the necessary experience had been garnered in controlling a spacecraft traveling at great distance from the Earth, the manned L1 program could begin. In the course of that program, cosmonauts would perform two or three flybys of the Moon and pass the Americans in that regard. The flights of unmanned lunar spacecraft in the American program had begun on 5 July 1966 with the launch of a mockup of the Apollo 2 spacecraft into near-Earth orbit. [*See G. M. Salakhutdinov, "The 'Apollos' Are Flying to the Moon" (1988, No 10).*]

Simultaneously with the testing of the L1 in unmanned mode, a broad program was to be conducted in the performance of scientific research that would include photographing the Earth and the Moon from space, studying the radiation conditions along the flight path and in circumlunar space, studying cosmic rays, and performing experiments with various biological objects.

In April 1967, under the name of Cosmos-154, a third model of the L1 was placed into near-Earth orbit. Because of a control-system failure that resulted in the premature jettisoning of the engines of the launch support system, the main propulsion system of the D unit did not fire.

With the 28 September 1967 launch of the fourth spacecraft, the new UR500K rocket began to demonstrate a "habit"—only five of the six engines of the first stage of the launch vehicle worked, and the launcher was destroyed. During that flight, the emergency rescue system was used for the first time. In the launch of the fifth spacecraft, on 22 November of that same year, the

launcher's first stage worked normally, but only three of the four engines of the second stage started. The emergency rescue system was triggered again, returning the reentry vehicle of the spacecraft to the ground. As the reentry vehicle was descending by parachute, the soft-landing solid-propellant rocket engine triggered unexpectedly at a high altitude.

Finally, on 2 March 1968, in the launch of the sixth spacecraft, the launch vehicle worked well, and the spacecraft, with the official name of Zond-4, was able to perform a flyby of the Moon and photograph it. In fact, that launch became the first launch on record. However, because of malfunctions in the operation of one of the sensors for the control-of-motion system, the attitude was incorrect just before reentry and separation of the sections, and therefore the reentry was ballistic and in an unplanned region, as a result of which the reentry vehicle was destroyed by the self-destruct system.

On 23 April 1968, during the launch of the seventh spacecraft, a short circuit in one of the units of the spacecraft's automatic control system on the segment of maximum dynamic pressure caused the emergency rescue system to trigger after the nose fairing was jettisoned during the segment of operation of the second launcher stage. On 14 July 1968, during launch preparations for the eighth L1, which was to take place on 21 July, the D unit oxidizer tank cracked because of overpressurization, and the launch failed to take place.

The second "recorded" launch was the launch of the ninth L1 spacecraft, which was placed into a lunar flyby trajectory on 15 September 1968 under the name of Zond-5; the spacecraft photographed the Earth from a distance of 85,000 km. On the return to Earth, operator error resulted in the failure of the gyro platform and the attitude-control sensor because of overheating. Trajectory correction was done with attitude-control fine-adjustment engines, and the reentry vehicle of the spacecraft, after a ballistic reentry, splashed down in the Indian Ocean. The vehicle was pulled out of the water by a Soviet search-and-rescue vessel.

The tenth spacecraft (Zond-6) lifted off on 10 November 1968 and performed a flyby of the Moon at a distance of 2,400 km from its surface, and it photographed the Moon twice—from a distance of 9,000 km and at maximum rendezvous. During the return of the spacecraft, the reentry vehicle's hull was depressurized because of a faulty rubber gasket, but that did not prevent the reentry vehicle from making a controlled descent in the Earth's atmosphere to the Soviet Union. On the parachute descent leg, depressurization of the parachute container as a result of the very same type of problem was recorded. Moreover, the parachute cords were fired early, and the reentry vehicle crashed. The photographic film, however, was pulled from the crumpled metal-clad cassettes, and excellent photos of the Earth and the Moon were produced.

The hopes of the cosmonauts of the "lunar detachment" to be able to soon make a flyby of the Moon were rapidly dissipating under the onslaught of the ever newer emergencies that were occurring with each new launch. The manned launches in the L1 program were postponed. In ferreting out the causes of the emergencies and overcoming the difficulties, our program, with time, fell behind the American program. Apollo 8, with a crew of F. Borman, J. Lovell, and W. Anders, was launched by a Saturn 5 rocket on 21 February [*sic*] 1968, and on 24 February [*sic*] it performed circumlunar flight. The political sense of continuing the circumlunar program of the L1 had been lost.

However, immediately stopping a flywheel once it has been started is virtually impossible. A program that had produced very satisfactory results couldn't be cancelled. Besides, the spacecraft were built, the launch vehicles were waiting. The schedule of flights had to be observed.

On 20 January 1969, because of problems in the operation of the LFREs of the second and third stages, the launch vehicle again had to be destroyed. The emergency rescue system, which had triggered, returned the reentry vehicle of the eleventh L1 spacecraft to Earth. On 8 August 1969, the twelfth spacecraft, under the name Zond-7 made a circumlunar flight 1,230 km above the surface and photographed the Earth and the Moon twice. There were virtually no glitches in the operation of the spacecraft systems, and on 14 August, after a successful controlled descent in the Earth's atmosphere, the reentry vehicle touched down south of the city of Kustanay just 50 km from the designated landing site. Theoretically, it was that very launch (at best) that could have been manned, but the leadership, after the triumph of Apollo 8, didn't want to give the "go ahead" to a manned launch.

The flights in the L1 program ended on 20 October 1970 with the launch of the thirteenth spacecraft in the series, under the name of Zond-8. After its flyby of the Moon 1,200 km above the lunar surface, the reentry vehicle returned across the North Pole because of a failure in an attitude-control sensor and made a ballistic descent into the Indian Ocean. The fourteenth and fifteenth spacecraft, equipped for manned circumlunar flight, went unused.

L3 Lunar Complex (OKB-1)

One of the objectives of the N1 launcher, according to the initial preliminary design, was to conduct missions to the Moon in a two-launch profile. Units launched in two ground launches would dock in near-Earth orbit, forming a spacecraft whose large mass would make it possible to perform a direct flight to the Moon. The entire spacecraft would land on the lunar surface, and after a stay on the Moon, the spacecraft's ascent stage, along with a return module, would lift off for a return to Earth. Such a mission would not be the most economical, but it would be reliable and easy to do.

In the development of lunar spacecraft both in the USSR and in the United States, various mission versions were evaluated, including the separation of a spacecraft into functional units. As demonstrated by the subsequent course of events, the United States regarded as optimal the version in which the spacecraft separated in circumlunar orbit. However, even in America, the "direct-flight" version itself was initially the primary version. It served as the basis in the preparation of the Apollo program proposed in mid-1961, after President J. Kennedy announced that America planned to land a man on the Moon before the beginning of the next decade.

In assessing that announcement and the course of the Apollo program, S. P. Korolev proposed accelerating operations in the Soviet Union to perform a lunar mission. It was thought that if the power of the N1 launch vehicle were increased and the characteristics of the lunar spacecraft optimized, the mission could be performed in a single-launch profile.

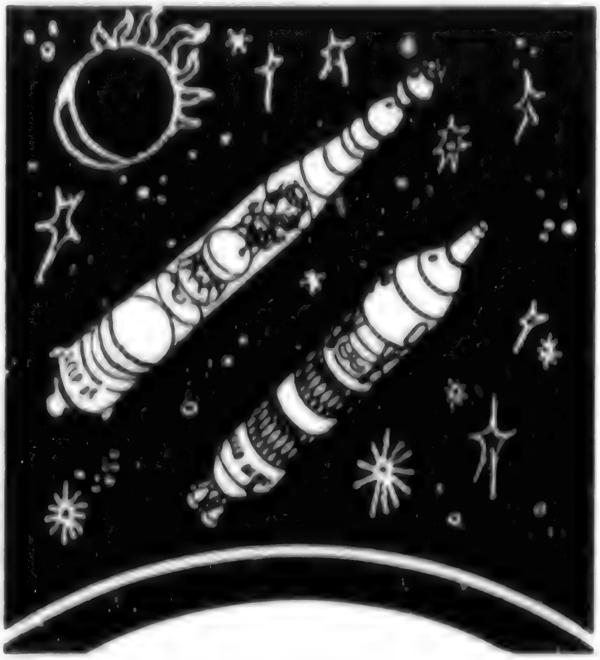
The early preliminary design of the N1/L3 lunar complex was signed by Korolev on 25 December 1964. In the context of that design, a Soviet mission landing one cosmonaut on the Moon while a second cosmonaut remained in circumlunar orbit would take place in 1967-1968 and would use one N1 launch vehicle and the L3 complex of spacecraft.

The N1/L3 lunar mission was to go like this. The N1 launcher, with a launch mass of nearly 2,750 tons, would place into a low near-Earth orbit 220 km high the L3 complex, which would have a mass of 91.5 tons. Since the designers expected to use an earlier developed preliminary design in the creation of the launcher, they could make only minimal corrections of the parameters laid out in that initial design. The mass of the L3 complex turned out to be near the maximum possible payload mass of the N1 version with 30 LFREs in the first stage.

The L3 complex, mounted beneath the nose fairing of the N1, consisted of a linkup of two rocket units and two spacecraft. The lunar orbital craft was the top half of the linkup. The crew would spend most of the flight in the complex's living quarters.

The lunar orbiter (LO) (see the figure) was developed on the basis of the Soyuz spacecraft and consisted of a reentry vehicle shaped like a headlight, living/working quarters of a new design with a larger exit hatch, an instrument-equipment section with an expanding conical "skirt." Inside the instrument-equipment section was a spherical fuel unit for the main propulsion system (MPS, or I unit) of the LO spacecraft. The unit, divided by a common baffle, served as a tank for the long-lasting, self-igniting fuel (nitrogen tetroxide/unsymmetrical dimethylhydrazine).

As with the Soyuz spacecraft, rescue of the L3 complex cosmonauts in the event of a launch-vehicle failure would be performed by using the emergency rescue system.



which had a powerful solid-propellant propulsion system, to carry the upper part of the spacecraft (the LO living/working quarters and reentry vehicle) clear of the launcher. A distinctive feature of the rescue systems of the lunar complex and the Soyuz spacecraft consisted in the fact that the part of the nose fairing being carried away with the L3 living/working quarters and reentry vehicle was stabilized because of the conical shape of the part being carried off and the balanced load secured at the top of the emergency rescue system propulsion system. The solid-propellant rocket engine of that system would carry the reentry vehicle quite far away, which was necessary because of the much larger mass of the launch vehicle and, consequently, the greater power of the blast that would result in a rocket failure.

Although it had much in common with the Soyuz spacecraft, the LO differed in its more complex electronics (systems for control, docking, communications, and telemetry), its high-capacity power supply sources based on fuel cells, its jet control system with low-thrust, two-component LFREs, and a main propulsion system developed virtually from scratch.

The conical "skirt" of the LO instrument-equipment section was joined to a cylindrical shell inside of which was the lunar lander (LL). The assembly was completed by two powerful rocket units. It should be noted that the highly efficient LFRE units, like the engines of the N1, would burn nontoxic oxygen-kerosene fuel. The launch from near-Earth orbit would be effected by the G unit, which would fire for 480 seconds to send the L3 complex into a translunar trajectory and then would separate from it.

After that, all maneuvers associated with a change in velocity on the translunar trajectory would be performed with the D unit's multiply fired LFRE with a thrust of 8.5 ton-force. That engine would be used to make a flight trajectory correction and transfer the complex to a circumlunar orbit with an altitude of 110 km, with a subsequent lowering of that altitude to 16 km. Then the complex's system would be checked, and the LO would separate.

Up to that time, the LL would be located inside the cylindrical adapter section, and the crew of the complex would control the flight from the living compartments of the LO. Just before the separation of the LO, one of the crew members in a Krechet semirigid space suit would use a mechanical arm/boom to perform an EVA, to transfer to the cabin of the LL. The second crew member would back up the first and be ready at any moment to go to his aid. For that, he would be wearing an Orlan space suit and would be in the depressurized living/working quarters of the LO, which would be used as an airlock chamber.

To people familiar with the American Apollo spacecraft, as well as with subsequent Soviet manned vehicles, the decision to transfer through open space might seem a bit strange. In this case, however, it was intimately intertwined with the specific configuration of the L3 complex and with the desire of the designers to reduce the number of spacecraft reconfigurations over the course of the mission as a whole, which would mean a minimum number of dockings. Upon careful analysis, the decisions made by the designers are entirely logical. Moreover, it should not be forgotten that the Apollo program was being laid out right before the eyes of the Soviet developers. Consequently, the reasons behind the decisions that were made were solid.

When the Soyuz spacecraft was under development, the idea of an internal transfer of cosmonauts through a hatch/crawlway in the docking unit was never raised. In laying out the L3 complex, it was decided that as soon as the one crew member arrived on the Moon, he would have to perform an EVA anyway, so he could perform an EVA to transfer from the LO to the LL. In addition, the designers, in moving away from an internal transfer and from the need to connect the electrical and pneumatic mains of the different spacecraft into a common network, went even further and suggested a unique docking unit designed exclusively for one docking. It consisted of an active assembly (a pin), which had very simple spring shock-absorbers, and a passive assembly (a flat, honeycomb hexagon). The requirements for precision in the alignment of the spacecraft were thereby lowered. It would be enough for the Aktiv spacecraft (the LO) to just place the pin anywhere in the plane of the passive docking assembly located on the LL. The pin would penetrate the honeycomb, and "claws" would pull the spacecraft together, providing a reliable mechanical connection adequate for the return transfer of the cosmonaut from the cabin of the LL to the LO. Not only were several hundred kilograms of mass thereby saved, but also a great many "tight spots" in the design were freed up.

The lander consisted of a spherical, pressurized cabin in which a cosmonaut, secured with special attachments, stood before an instrument panel and a landing viewport. As with the American spacecraft, the seat in the LL cabin was left out to save mass. The cabin contained some of the life-support systems, various display instruments, etc. Most of the equipment had been removed from the cabin and placed in the sealed cylindrical instrument section mounted on the outside of the aft part of the cabin. On the upper part of the cabin were the docking assembly and the attitude-control vernier LFRE unit. On the lower part of the cabin were the Ye rocket unit, the lunar landing assembly, and additional instrument compartments.

After one of the cosmonauts took his position in the cabin of the lander, the LO would separate from the cylindrical adapter section. Then the adapter section would be "pulled off" the lander. There would be enough fuel left in the D unit tanks, which were protected by a strong cryogenic thermal insulation. After its engine was fired, the linked rocket unit and LL would leave orbit and brake. At an altitude of approximately 1.5-2 km, the braking would end with the jettisoning of the empty D unit. At that point, the LL would be performing independent flight.

Maneuvers involving the lander's descent, its hovering over the lunar surface, and its soft landing would be performed with the Ye unit's single-chamber 2050-kgf LFRE, which could be heavily throttled and had a broad range of thrust regulation. The engine burned nitrogen tetroxide/unsymmetrical dimethylhydrazine and was backed up by a two-chamber LFRE with roughly the same thrust.

That LL landing profile also differed from the American profile. It was based mainly on the large specific impulse of the D unit LFRE and, as a result, its high degree of thriftiness. Besides, there was no need to develop a special landing stage that would have to be used to suppress most of the velocity during the vehicle's descent from circumlunar orbit and its soft landing.

Thus, the lander would hover at an altitude of several dozen meters above the lunar surface. Its engine would enable maneuvering (also spanning several dozen meters) during the landing approach so that the vehicle could steer away from detritus or a crater slope. Ground-based experiments with a model of the lander demonstrated that landing on a steep crater slope would be very dangerous for the LL and could result in the capsizing of the vehicle, which would mean that the cosmonaut couldn't return to the orbiter.

The cosmonaut would visually select a landing site, and the LL would descend to the surface several seconds later. The entire landing procedure, after the D unit separated from the LL, would take a little over a minute. The possibilities for maneuvering the LL over the lunar

surface were extremely limited. In the event that a soft landing couldn't be made, LFRE thrust would be increased to maximum to put the LL back into circumlunar orbit for a rendezvous with the lunar orbiter.

In a landing that went well, the lander would set down on the surface of the Moon with lunar landing gear consisting of a ring around the Ye unit and four landing supports affixed to the ring. The landing supports (or legs) would, in principle, be similar to the landing supports of the Apollo LM or to the supports of the Soviet unmanned Luna-16, and they would consist of cylindrical struts with honeycomb energy-absorbing elements, braces that would take the lateral loads, and saucer-shaped footpads for setting down on the surface. The parameters of the landing gear were determined on Earth in the course of a series of experiments involving the landing of a model of the LL on soils with various mechanical properties.

Four solid-propellant "hold-down" rocket engines were fired the moment the lunar landing gear legs came in contact with the soil in order to prevent the LL from hopping or overturning at touchdown on the lunar surface. The effectiveness of using such a technique to stabilize the vehicle was also confirmed on Earth—both in Earth's gravity and on a stand that simulated the Moon's gravitational force.

After landing, the LL would begin its operations on the lunar surface. The lander was designed to function independently for 72 hours. For 48 of those hours, it could be on the lunar surface, although that amount of time would have to be shortened to only a few hours during the very first missions. The cosmonaut's space suit would allow him to work outside the spacecraft for about an hour and a half. After landing, the cosmonaut would ascertain the status of the vehicle's systems and would prepare for egress. In doing so, he would check the seal of the space suit and depressurize the cabin. After opening the port-side hatch, the cosmonaut would exit to the platform on the lunar landing gear and would descend along a ladder to the lunar surface.

The operations on the Moon would consist in planting the USSR state flag, deploying the scientific instruments, collecting lunar soil samples, and photographing the terrain, as well as conducting television reportage from the lunar surface. The arsenal of the scientific instruments at the disposal of the Soviet cosmonaut would be extremely restricted by the low weight of the cargoes that the LL could carry.

A complex problem associated with only one man being on the Moon was the possibility of the cosmonaut falling on his back. In the awkward, inflated space suit, he would be like a turtle on its back. The designers thought of a rather clever way out of that precarious situation by furnishing the cosmonaut with a light-weight hoola-hoop-type hoop that he would don as he descended to the lunar surface. The hoop was secured in a catch on the waist of the space suit and was located primarily in the back, so as not to interfere with the cosmonaut's work. If the cosmonaut fell on his back, the hoop would enable him to quickly roll over on his side or his stomach and pick himself up normally. That device was tested in an aircraft in which lunar gravity was simulated.

After a brief visit to the lunar surface, the cosmonaut would climb back into the cabin, secure a sealed container of the lunar soil samples inside it, secure himself, and then pressurize the cabin with air. After that, he would take off the space suit and rest. Later, he would perform operations in preparation for his return.

At a moment in time dictated by the position of the LO in circumlunar orbit relative to the LL on the Moon itself, the electrical, pneumatic, and mechanical links of the lunar landing gear and the Ye unit would be severed. The unit's engine would then fire, and the LL would lift off from the Moon. After a brief segment of vertical lift, the trajectory for LL insertion would bend smoothly, and traveling almost parallel to the surface, the vehicle would enter a low circumlunar orbit. At that point, the pilot of the LO, which would assume the role of an "active" vehicle, would perform a rendezvous and docking, using in the process a powerful radar scanning system, plus the convex viewport of the living/working quarters to make visual observations of the docking. The maneuvering of the LO was done with a multiple-ignition, 417-kgf LFRE mounted in the center of the aft section of the I unit. After docking, the cosmonaut in the LL would transfer through open space to the living/working quarters of the orbiter, bringing the soil-samples container with him.

The lunar lander, no longer needed, would be jettisoned, and the luner orbiter would use its powerful two-chamber 3300-kgf LFRE—whose chambers would be mounted on the sides of the maneuver engine—to enter a trajectory for a return to Earth. Just before the completion of the return to Earth, the compartments of the spacecraft would separate, and the reentry vehicle would enter the atmosphere. After a controlled reentry at fairly small g-loads, the vehicle would land in a designated region of the USSR.

To get the bugs out of the L3 complex before manned flight, an enormous program of ground tests was conducted for the individual assemblies and systems, as well as for both spacecraft as entire systems. Besides ground tests, there were general rehearsals of the operation of the LO in space flight. To test the LO in circumlunar orbit, an unmanned version of it was created—the T2K. The assemblies and systems of the T2K generally matched the systems of the lunar spacecraft. The vehicle was launched with a Soyuz booster equipped with a unique, specially developed "large-caliber" fairing; however, the landing supports of the spacecraft would not fit under the fairing, and were absent on the T2K version.

The first launch of the T2K took place on 24 November 1970, at Baykonur, under the name of Cosmos-379. After entry into a low near-Earth orbit of 192-232 km in altitude and separation from the last stage of the

launcher, the Ye unit LFRE was fired three and a half days later and, under heavy throttling, increased somewhat the speed of the vehicle and simulated the hovering of the LL over the lunar surface. As a result of that maneuver, the altitude of the orbital apogee of the vehicle increased to 1210 km, and the period of revolution, to 99 minutes. After various checks of the onboard equipment, with simulation of a stint on the Moon, the lunar landing gear was jettisoned after day four, and the Ye unit engine was fired for the second time. At maximum thrust, it increased the speed by more than 1.5 km/sec, simulating entry of the LL into circumlunar orbit for a rendezvous with the LO. As a result of that maneuver, the altitude of orbital apogee of the T2K rose to 14,035 km, and the period of revolution, to four hours. After that, the vehicle spent some time in a stabilization mode, simulating maneuvers in the rendezvous and docking with the LO.

The second launch of the vehicle took place on 26 February 1971. It got the name Cosmos-398. The second program for the orbital flight of the T2K by and large duplicated the first. As a result of the two firings of the Ye unit's LFRE, the spacecraft went into an orbit with an altitude of 203-10,903 km. During the third orbital flight (Cosmos-434, launched 12 August 1971), the firing of the LFRE in throttle mode was the longest burn of the three flights, and after the second firing, the spacecraft went into an orbit with an altitude of 186-11,804 km.

The successful launches of the T2K vehicles confirmed the high degree of reliability of the systems and equipment of the lunar lander and the possibility of using that vehicle for a manned flight to the Moon.

With regard to the T2K launches, it is interesting to note that in the early 1980s, a report about the impending fall of the spent Cosmos-434 Soviet satellite caused concern among the public in the West. Foreign observers advanced a notion that the satellite carried a nuclear reactor on board. However, because of the fact that that vehicle has been launched during the "race to the Moon," had maneuvered in orbit, and had transmitted telemetry signals typical of manned Soviet spacecraft, some Western reviewers felt that it was an unmanned version of a manned spacecraft. Later, as it gradually dropped into the atmosphere, the satellite finally burned up over Australia.

To dispel the fears associated with that event, an official representative of the USSR Ministry of Foreign Affairs assured Canberra that there were no radioactive materials aboard Cosmos-434 and that the satellite was simple an "experimental unit of a lunar module"! Of course, that was the vehicle that the Western observers had been talking about the whole time.

The term "lunar module" (or in Russian, *lunnaya kabina*) was used to designate the unit of the Apollo spacecraft that was designed to land on the Moon. It was clear that the primary purpose of a vehicle like the Cosmos-434 was flight in manned, not unmanned mode.

Somewhat before the T2K flights, flight tests of the N1 began in near-Earth orbit. In January 1968, a mockup of the N1 was erected on the launch pad at the Baykonur cosmodrome; the mockup was designed for systems debugging on the ground and for training the crews of the launch complex. And then finally, on Friday, 21 February 1969, at 1217:55 hours Moscow time, the first launch of the N1 launch vehicle (the first flight article No 3L) took place. Instead of the orbiter and lander, the rocket's payload was a simplified L1 spacecraft.

During liftoff, in the interval between seconds 3 and 10, a spurious command issued by the KORD system shut off the A unit's LFREs Nos. 12 and 24, which were performing well. At 66 seconds, the elevated vibration caused by acoustical loads ruptured a line that feeds oxidizer to the gas generator of one of the LFREs; the leaking liquid oxygen started a fire in the aft section. The rocket could have continued the flight, because the fire was growing rather slowly, but at 70 seconds, a general command shut off all the LFREs of unit A. The engine developers feel that the logic of the command to shut down the entire system was wrong in that case. The emergency rescue system triggered; the reentry vehicle of the L1 spacecraft, which was to perform a flyby of the Moon on that flight, landed several dozen kilometers from the launch site.

The source of the problem was that the engines were not adequately tested, because there was no vibration stand for testing.

The second launch of the N1 (article No 5L, with payload of a simplified L1 spacecraft) took place on Thursday, 3 July 1969, at night. Just 0.4 second after the command "Vertical contact" [kontakt podyem], a metallic object that got into the oxidizer pump caused the A unit's No 8 LFRE to explode. In the explosion, the onboard cable system was broken up, adjacent engines were damaged, and the lower part of the stage began to be destroyed. A fire broke out in the aft section, and the rocket began to fall. The emergency rescue system again triggered. The flight lasted 18 seconds. The LFREs of the other sectors worked well during that time. The rocket fell onto the launch pad, exploded, and destroyed the launch complex.

The cause of the failure was determined from an analysis of the launcher fragments. As early as in the stand testing of the LFREs, it had been determined that the engines were susceptible to the entry of large metal objects (dozens of millimeters in diameter) in the oxidizer pump. They would damage its rotor and destroy the pump; small metal fragments (shavings, filings, etc.) that passed through the pump and burned in the gas generator would form intermetallic compounds on the turbine vanes and destroy the vanes. Nonmetallic objects (rubber, fabric, etc.) that entered the inlet of the turbopump assembly did not stop engine operation. Article No 5L had no filters at the pump inlets. In addition, the system for flushing the huge tanks and lines of the N1 had not yet been perfected. After filters were installed on

article 8L, no such failures would occur. Moreover, that article had a powerful freon fire-extinguishing system, new, reusable engines, and a modified KORD system. The rocket was considerably heavier, but such fires were eliminated.

The third launch of the N1 (article 6L, with payload of lunar orbiter and lander mockups) was performed on the second (undamaged) launch complex at Baykonur on Sunday, 27 June 1971. Soon after the liftoff, unexpected gas-dynamic moments (eddies and counter currents) at the base caused the rocket to roll. The rate and angle of roll grew steadily. At 39 seconds, the gyroscope-stabilized platform of the launcher control system hit its stops, and at 48 seconds, the large amount of torque started the destruction of unit B. The emergency rescue system was only a mockup and, naturally, did not fire. At 51 seconds, when the angle of turn reached 200°, the KORD system issued a command that cut off all engines of the first stage.

An investigation of the causes of the failure revealed that the torque reached 43 ton-force/meter, and the vernier nozzles for roll were unable to counter it. The propulsion system worked well during that launch.

The fourth launch (article No 7L, equipped with additional vernier LFREs in the first and second stages, for better control in the roll channel; payload, a full-scale lunar orbiter and a mockup lander) was performed on Thursday, 23 November 1972. The start and liftoff went well. At 90 seconds, according to the cyclogram, six LFREs of the core propulsion system of unit A were cut off. Then, apparently because of large nonstationary loads caused by a water hammer when the core propulsion system was shut off abruptly, lines for feeding fuel to the LFREs of the core propulsion system burst, and a fire broke out. The failure developed within a matter of one or two seconds. The rocket continued its flight and exploded at between 107 and 110 seconds, when the fire in the aft section reached a critical point. The emergency rescue system triggered soon after that.

An investigation established that the abrupt shutdown of the LFREs led to fluctuations in the fluid column in the feeder lines. They ruptured, and a large amount of fuel spilled onto the shut-down, but still hot engines and into the section with LFREs still operating. The fire and the explosion were unavoidable. Either the LFREs would have to be shut down smoothly, or oscillation dampers would have to be installed in the lines, which was to be taken care of for article 8L.

In the opinion of many specialists, to produce test results for the flight, there needed to be a provision for a command from Earth to remove blockings from the system for separating the stages, making an emergency removal of the damaged first stage (unit A), and firing the LFREs of the second stage. Because of the remaining seven seconds of operation, the first stage did not "hit its stride" at the full 165 m/sec, which could have been easily compensated for by increasing the time of operation of the subsequent stages, and also by lowering the altitude of the payload injection orbit a little.

Unfortunately, the operations in the N1/L3 project were never able to hit full stride, and after the American astronauts landed on the Moon, the USSR leadership completely lost interest in the program. The operations were put on hold and, later, were frozen for real. The fifth launch of the N1 (article No 8L) had been slated for August 1974, and the N1 had reliability indices that were considerably improved and was to carry a full-scale L3 complex (which was to perform a flight to the Moon that included the entire program, but in unmanned mode). The launch, however, never took place. With the change in the leadership of the Energomash Central Design Bureau, the N1/L3 program was ended.

LK-700 Spacecraft Project for a Lunar Landing (OKB-52)

After the program for a manned flyby of the Moon was transferred from OKB-52 to OKB-1, V. N. Chelomey, in striving to make up for what had been lost and to set up a competition with the N1/L3 project, attempted to produce a design of a spacecraft for a landing on the Moon. That space craft was designed for the UR700 rocket, which was capable of carrying 130 tons and whose experimental design was being analyzed in branch No 1 of OKB-52. At a plenary session (16 November 1966) of the advisory council reviewing the course of the work being done in the N1/L3 program, Chelomey submitted a proposal for the creation of the LK700 (see the previous figure).

The concept underlying that spacecraft was largely unique. In striving to simplify operations associated with the reconfiguration of the spacecraft as much as possible, and thereby improve the mission's reliability, Chelomey proposed making a direct flight to the Moon. However, calculations showed that that would require building a launch vehicle that would have to lift approximately one and a half times what the N1 could lift. OKB-52 began working on the design of that rocket almost at the same time that the medium-lift UR500K (Proton) booster rocket was being developed. The principal requirement of the new launcher was that it be transported in modules from the manufacturing plant to the cosmodrome, where it would be rapidly assembled, checked, and launched.

The profile for a "direct" mission with the UR700/LK700 was virtually the same as the "direct" version of the Nova/Apollo, which the Americans had rejected in early 1961. It called for placement of a spacecraft and an upper stage into near-Earth orbit and a subsequent launch from orbit to the Moon. Braking and entry of the spacecraft into circumlunar orbit, as well as the descent from orbit and decrease of the main velocity, would be done with a special retrorocket unit. Several kilometers above the lunar surface, the retrorocket unit would be jettisoned, and a soft touchdown of the spacecraft on landing legs would be achieved by throttling the LFRE of

the ascent stage, as would be done in the lunar lander of the N1/L3 program. The LFREs of all the units, as well as the engines of the UR700 launchers, would have to burn nitrogen tetroxide/unsymmetrical dimethylhydrazine.

The two cosmonauts of the LK700 spacecraft would be in a return module similar to the module developed for the UR500K/LK1 flyby program.

After the mission tasks associated with the visit of the crew to the lunar surface had been performed, the landing attachments would be separated and LFRE of the ascent stage would fire, operating at full thrust. After lifting off from the Moon, the LK700 could either first enter a circumlunar orbit and then leave from it for Earth (one version of the project) or it could immediately enter a flight trajectory for Earth (second version). After a flight trajectory correction had been made with the LFRE of the ascent stage, the return module would have to separate just before arrival at Earth, with subsequent reentry into the atmosphere, controlled descent, and a parachute-assisted landing.

Relying on what was developed in OKB-52, Chelomey tried to convince the leadership of the sector that, with financial support and the research base that had been created in previous operations, his OKB would be able to execute the program quickly and make the USSR the first to land on the Moon. He was supported in that by V. P. Glushko and several other chief designers. The advisory council, however, considered such a declaration too bold and allowed only the performance of preliminary design work on the UR700/LK700 complex. The development of the spacecraft and the launcher, performed in the framework of routine scientific research, continued until the early 1970s, at which point the lunar exploration program was reoriented from manned flights to unmanned flights.

V. N. Chelomey proposed after that the rather ambitious MK700 spacecraft for a flight to Mars. The spacecraft would be launched by the superheavy-lift UR700M booster, which would be capable of lifting 240 tons. But even as the proposals for that program were being developed, it became clear that the impact of the first flight of a man to Mars on public opinion would be disproportionately small, by comparison with the material expenses that would attend the flight. The project never went any further.

N1/L3M Rocket/Spacecraft Complex Project (Energomash Central Design Bureau)

Seeing how unhappy the sector leadership was about continuing to finance the N1/L3 project, which had not fulfilled the sector's hopes for prestige, OKB-1, at the suggestion of V. P. Mishin, began developing an improved version of the lunar rocket-space complex, the N1/L3M, for which the N1 launcher would be augmented and a new spacecraft would be created for a mission to the Moon in the context of a two-launch profile. The designers calculated that by 1978-1980, with financing that would not exceed the routine financing of the standard N1/L3 program, the USSR would be capable of steadily developing the necessary infrastructure for creating a lunar base and for conducting lunar missions of average duration (up to three months).

One of the biggest difficulties attending the N1/L3 project was acknowledged to be the lack of reliability in the docking of the lunar orbiter (LO) and the lander (LL) after it ascended from the lunar surface, a difficulty that stemmed from the poor capabilities of the electronic systems of the two spacecraft, the poor knowledge of navigation conditions near the Moon, and the impossibility of rendering the cosmonauts comprehensive support from Earth, as could be done in a docking of spacecraft in artificial Earth satellite orbit. New solutions would be required.

Since the lifting capability of even an augmented N1 would not enable the execution of a direct mission to the Moon within an extremely brief period of time, it was decided to develop a modified version in which the retrorocket unit and the lunar spacecraft would be launched into near-Earth orbit by separate N1s and then placed individually, by their own booster rockets, into translunar trajectories. Separate orbital launches from near-Earth orbit would eliminate the need to build one powerful booster. Docking would take place after the two craft entered circumlunar orbit. The lander and the retrorocket would link up in the first period of the mission—i.e., before the landing on the lunar surface. In the event that the lunar spacecraft couldn't dock, it would use its own propulsion system, with no special risk, to launch from circumlunar orbit in the direction of Earth. If the docking were successful, the retrorocket unit would be used for effecting the descent of the spacecraft from circumlunar orbit and decreasing most of the velocity. The soft landing would be accomplished with the propulsion system and the landing legs of the spacecraft. After that, the profile of the mission resembled the profile of the mission proposed by the Mashinostroyeniye Central Design Bureau (MCDB) in the UR700/LK700 project.

The N1/L3M program called for broad use of the research base developed in the N1/L3 program. A number of versions of the lunar spacecraft had been examined. For example, one version put the cosmonauts at launch from Earth in the reentry vehicle, which was secured to the upper part of the craft. When performing in-flight operations and just before touching down on the Moon, they would move through a crawlway-chute to the living/working quarters of the craft, which was mounted beneath the reentry vehicle. In a different version, above the propulsion system of the spacecraft was a cocoonlike living compartment, inside the upper part of which the reentry vehicle was secured. A large part of the service equipment of the spacecraft was located in a sealed, cylindrical instrument section inside the living compartment. During various operations in flight and on the lunar surface, the cosmonauts would leave the reentry

vehicle and work in the interior of the living compartment, which provided not only free access to the control instruments, but also a good view, which would make choosing the landing site easier. Upon return to Earth, the living compartment would separate and the reentry vehicle would exit it just before reentry.

By 1972, the upper echelons of the country's leadership had no interest whatsoever in a manned study of the Moon. After the successful American Apollo program, the lunar program lost its prestige. In addition, because of the delay and the gradually freezing of the N1/L3 project, the program for exploring the Moon was reoriented toward unmanned studies. The number of flights of unmanned probes to the Moon gradually diminished, and the program was subsequently closed down in 1976.

Almaz and Salyut Orbital Stations (Mashinostroyeniye Central Design Bureau and Energomash Central Design Bureau)

The idea of a manned space station, which was advanced by K. E. Tsiolkovskiy, first found its embodiment in the sketches made by S. P. Korolev even before the launch of the first satellite. They were sketches of vehicles meant for long-duration stays by man in space. Later, those ideas were merged with the research involving Soyuz. Korolev assumed that he would be able to realize that notion of a manned station, but he was so overloaded with other work, he wasn't able to do it.

Work in the United States involving orbital stations took on a decidedly military orientation shortly after it got under way. So as not to fall behind America in that regard, the Soviet Union in the mid-1960s conducted research on the creation of manned stations. In addition to OKB-1, which planned on building a station by assembling it in orbit, OKB-52, headed by V. N. Chelomey, was also involved in the work.

The work on the design of an orbital station in OKB-52 can be said to have started on 12 October 1964, when the general designer proposed to the staff members of the enterprise that they begin developing a manned orbital station that could be visited, would have changing crews of two or three people, and would have a service life of one or two years. The station would be intended for solving problems involving issues of science, the national economy, and defense and would be placed into orbit by the UR500K launcher. The preliminary design of the station—or more precisely, of the rocket-space system that had received the name Almaz—was adopted in 1967 by an interdepartmental commission made up of 70 renowned scientists and heads of design bureaus and research institutes of industry and the Ministry of Defense.

Almaz was conceived as a space-based observation point with comfortable conditions for the crew and good observation equipment, plus an accurate pointing system, and it would be capable of tracking forest fires and pollution of seas and rivers, as well as military troop movements.

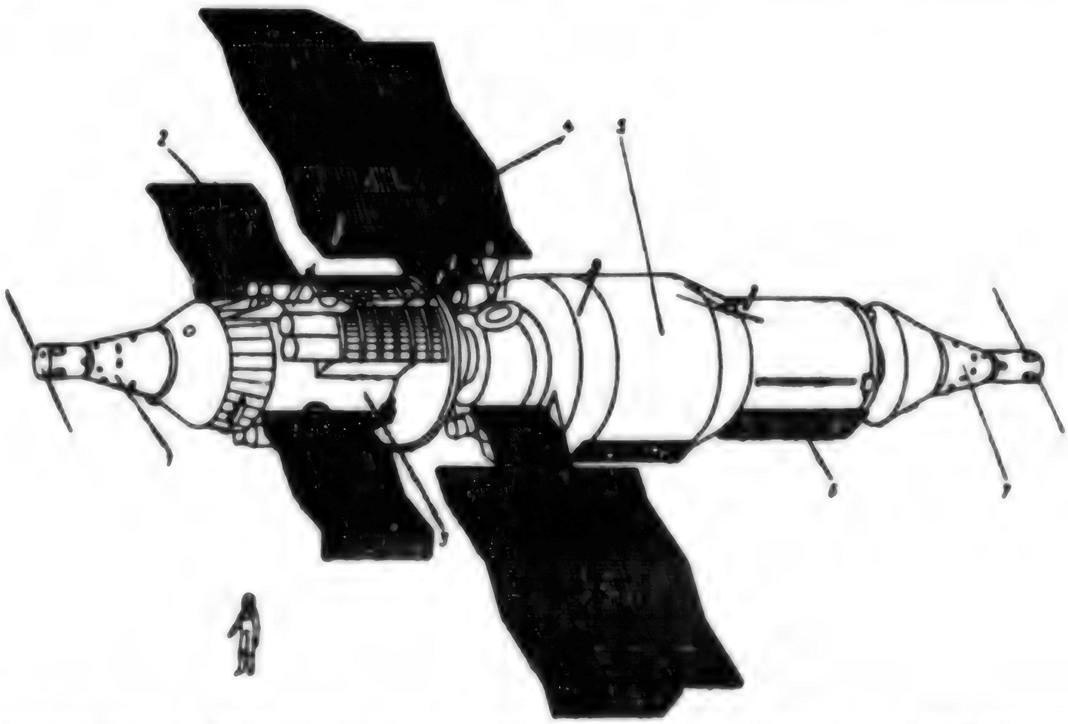


Figure 4. Initial design of Almaz system: 1 and 7—return capsules; 2 and 4—solar panels; 3—TSC functional/cargo unit; 5—Almaz station; 6—Side-looking radar

The station's own transport/supply craft (TSC), which would be launched by that same UR500K, would be developed for delivering crew and supplies to the station. Initially, both the station and the TSC were to be equipped with the same type of return capsule designed to take a crew from orbit (Fig. 4), but the idea was quickly abandoned, and only the TSC was left with a return capsule.

The Almaz station was set up for long-duration work of a crew of three people. In terms of design, the pressurized compartment of the station was divided into two areas that could be arbitrarily called a large-diameter area and a small-diameter area. The small-diameter area was located in the forward part of the station and was enclosed during launch inside a conical nose fairing. Behind it was the large-diameter area. Transport craft would dock at the aft end of the station, where there was a spherical airlock that communicated with the pressurized compartment by way of a large transfer hatch. The aft part of the airlock had a passive docking port; the upper part of the airlock had a hatch for egress into open space; the lower part of the airlock had a hatch that communicated with the chamber from which one could send capsules with research materials to Earth. The capsule had its own propulsion system, a parachute system, a jettisonable thermal-protection shield, and a descent compartment with a beacon. After the necessary orientation just before release from the station, it was spin-stabilized just before firing of the propulsion system. Around the airlock were assemblies of station engines, deployed antennas, and two large solar panels. The aft end of the station, with the airlock, was enclosed by a cone-shaped shield consisting of vacuum-shield thermal insulation.

In the forward part of the pressurized compartment, in the small-diameter area, was a crew living compartment, with sleeping areas, a dining table, a chair for resting, and viewports for photography.

Behind the living compartment was a working compartment, with a control console, a work station, an optical sight that made it possible to stop the travel of the Earth's surface and observe isolated details, a panoramic-coverage device for a broad view of the Earth, and periscopes for examining the space around the station. The aft part of the pressurized compartment was occupied by observation gear and the control system.

A large optical telescope for observing the Earth took up the space behind the working compartment from floor to ceiling of the station. Plans were to photograph sectors of land and sea, develop the film right on the station, analyze it and its more interesting frames, and send them back to Earth by the television link. The rest of the film could be sent back to Earth in the capsule.

In light of the fact that when the Almaz station was under design, the United States was doing work on various types of space-based inspector/interceptor satellites, measures were taken on the station to provide protection against such interceptors and tow craft: the station was equipped with an A. E. Nudelman rapid-fire aircraft cannon that could be aimed at the proper point through a gun sight by turning the staion. Almaz, of course, couldn't attack anyone—those were simply means of self-defense.

The work on the Almaz rocket-space system was divided like this: the project as a whole, the station itself, and the return capsule of the TSC were being developed in Chelomey's head organization, the Mashinostroyeniye Central Design Bureau (MCDB); the TSC (its functional/cargo unit) was being developed in branch No 1 of that design bureau. The UR500K rocket was also being designed there. The station, the spacecraft, and the launcher would be manufactured at the Khrunichev Machine Building Plant.

In the first stage of development of the Almaz system, the crews would have to be delivered to the station on Soyuz spacecraft. Cooperation in that regard was set up between the MCDB and S. P. Korolev's OKB (the Energomash Central Design Bureau, or EMCDB).

The client assigned the developers of the Almaz system very complex specifications in terms of equipment characteristics and the reliability and duration of its operation. And if by late 1969, the work in the development of the hulls of the station and certain service systems was right on schedule, the work on the instrumentation of the station was dragging.

By 1970, the hulls of eight test-stand units and two flight units of the station had been built, and ground testing of the station's systems was under way. Crew members had been chosen for the flights to the station, and training was under way in the Cosmonaut Training Center.

For various reasons, however, under pressure from the leadership of the ministry of general machine building, the manufactured hulls, the equipment, some of the gear, and the documentation were transferred to the EMCDB, where within less than a year, in cooperation with the branch No 1 of the MCDB, a long-duration orbital station (LOS)—Article 17K—was created on the basis of the Almaz station and Soyuz spacecraft systems.

The LOS differed from the Almaz station in that it had an adapter section in the forward part of the small-diameter area, and the Soyuz spacecraft would dock with that section. In the aft part of the station was a modified Soyuz-spacecraft instrument-equipment section. The power supply for the station would come from four fairly small solar panels, also taken from the Soyuz spacecraft and mounted in pairs near the small-diameter area and the instrument-equipment section. In terms of instruments, the LOS also had little in common with the Almaz station, which had much more gear.

In connection with the acceleration of the work on the LOS, the EMCDB quickly developed a transport version of the Soyuz spacecraft that had a newly designed docking assembly, for flights to the station.

LOS-1 was launched 19 April 1971, under the name of Salyut. Soyuz-10 lifted off on 23 April 1971, to deliver a crew to the station. But the crew (V. A. Shatalov, A. S. Yeliseyev, and N. N. Rukavishnikov), after docking with the station, was unable to transfer to the station, because of a defect in the docking port. A second crew lifted off on 6 June 1971, aboard Soyuz-11. This time, cosmonauts G. T. Dobrovolskiy, V. N. Volkov, and V. I. Patsayev got into the Salyut station. After 24 hours of work on the station, the Soyuz-II crew, on its return to Earth, perished tragically, because of a depressurization of the reentry vehicle.

Based on the work of the first Salyut station, LOS-2 was prepared. The launch attempt on 29 July 1972, however, was unsuccessful, because of a booster failure during the second-stage operation.

Meanwhile, at the MCDB and the Khrunichev plant, work on the first Almaz was proceeding. Ground-based debugging of the station in the comprehensive testing of all the systems was completed by 1973.

After a three-month preparation for liftoff, the first Almaz station was launched to orbit on 3 April 1973 and received the name of Salyut-2. During autonomous flight, in which all the station systems were checked, the station depressurized on the 13th day of flight, and all the systems gradually failed. After analysis of the telemetry data, the most probable cause of the failure was acknowledged to have been a malfunction in the propulsion system that led to punctures in the station hull. Salyut-2 gradually descended from orbit and fell into the ocean.

Under way at that time at the Khrunichev plant was the construction of LOS-3, which was somewhat different from the LOS-1 and -2 stations. In particular, the station would use three large steerable solar panels intended for the TSC, which would more than double the capacity of the power-supply systems and would eliminate the need to keep the station pointed at the Sun. The station also had differences in the instrument-equipment unit. After injection into orbit on 5 November 1973, the ion sensors in the station's attitude-control and control-of-motion system malfunctioned, leading to the depletion of all the fuel by the attitude-control engines. The station, which had been called Cosmos-637, performed passive flight for some time. After a command was issued to raise the orbit, an improper attitude caused the LOS to enter the atmosphere and destroy itself.

Work on the Almaz manned station continued. After a detailed analysis of the efficiency of the systems in the Salyut-2 flight, Almaz-2, under the name of Salyut-3 was placed into orbit on 25 June 1974; the design was modified to enhance reliability. The autonomous flight

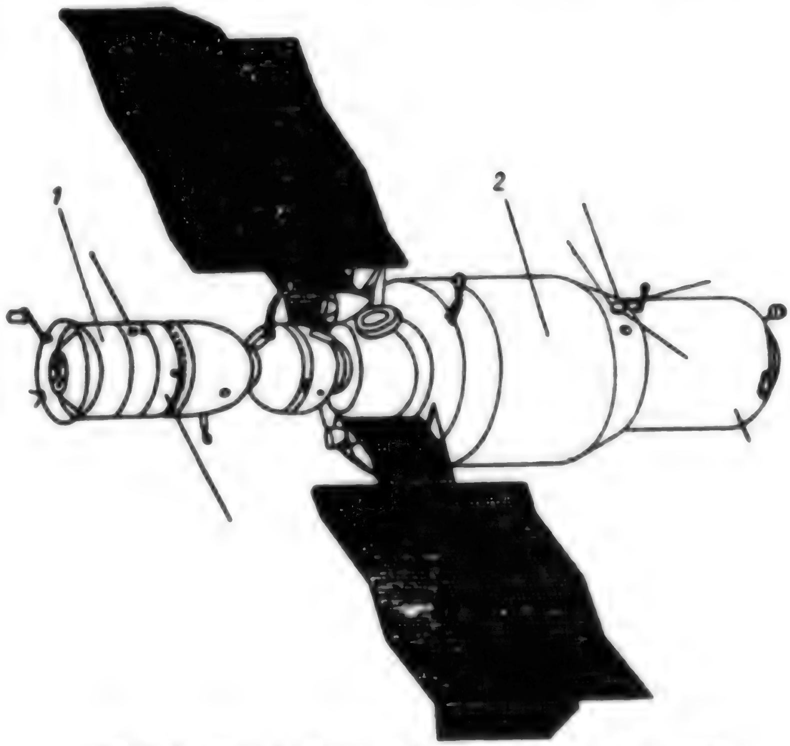


Figure 5. Salyut-3 (Almaz-2): 1—Soyuz-14; 2—Almaz station

of the station went successfully. On 3 July 1974, pilot-cosmonauts P. R. Popovich and Yu. P. Artyukhin successfully docked Soyuz-14 with the station and boarded it. The station (Fig. 5) began operation in manned mode.

After successfully executing the flight program, the crew returned to Earth on 19 July 1974, aboard Soyuz-14. The reentry vehicle touched down in the vicinity of Dzhezkazgan.

On 26 August 1974, Soyuz-15, with a crew of G. V. Sarafanov and L. S. Demin, lifted off for the station. A malfunction in the rendezvous system, however, prevented the docking. On 28 August, the Soyuz reentry vehicle landed in the vicinity of Tselinograd. No other Soyuz spacecraft were earmarked to continued operations with the station.

Upon command from Earth, Salyut-3, after fully performing its duties in autonomous flight in the context of the main program and other programs, descended from orbit on 24 January 1975 and sank in the Pacific Ocean.

The launch of LOS-4, under the name of Salyut-4, took place on 26 December 1974. It should be noted that although plant capacities made it possible to be manufacturing two types of stations—the Almaz and the LOS—at the same time, the control-and-telemetry complex was not able to control two manned stations in space simultaneously. Control of just one station required intensive, round-the-clock work at all ground stations, especially during manned missions. That is why the launches of the Salyut stations were done as they were—sequentially.

Two manned missions to Salyut-4 were performed: the first was Soyuz-17 (11 January 1975 launch, 9 February 1975 landing, with a crew of A. A. Gubarev and G. M. Grechko), and the second was Soyuz-18 (24 May 1975 launch, 26 July 1975 landing, with a crew of P. I. Klimuk and V. I. Sevastyanov). On 5 April 1975, a crew of V. G. Lazarev and O. G. Makarov lifted off to the station, but the Soyuz craft never entered orbit, because of a problem that occurred in the jettisoning of the aft section of the third stage of the launcher. The cosmonauts flew a ballistic trajectory in the reentry vehicle and landed 21.5 minutes after liftoff.

An unmanned Soyuz-20 was launched to Salyut-4 on 17 November 1975, to conduct service tests of the assemblies and systems while in joint, long-duration flight. The Salyut-4 LOS ceased existence on 3 February 1977.

The launch of Almaz-3 (Salyut-5) took place on 22 June 1976; a crew of B. V. Volynov and V. M. Zholobov went up to the station on 7 July, aboard Soyuz-21. The crew was to work aboard the station for about two months, but an abrupt turn in the health of Zholobov ended the flight on 24 August. In an analysis of the work done by the cosmonauts, a joint medical commission reached the conclusion that the syndrome observed in the flight was a result of the crew being overworked and of emotional stress. The cosmonauts did not get enough sleep, they broke the physical training routine, and they didn't get enough psychological support from the ground.

To gather evidence of the suitability of the Salyut-5 station for further operation, a crew of V. D. Zudov and V. I. Rozhdestvenskiy went aloft on 14 October 1976, aboard Soyuz-23. The spacecraft could not dock with the station, however, because of a problem with the antenna of the spacecraft's rendezvous homing head. On 7 February 1977, the possibility of continued operation with the station was finally confirmed by the crew of V. V. Gorbatko and Yu. N. Glazkov, who had gone aloft in Soyuz-24. After completing the flight program, the crew returned to Earth on 25 February.

The flight of Salyut-5 ended on 8 August 1977, when, after firing a braking impulse, it entered the dense layers of the atmosphere above a designated region of the Pacific Ocean.

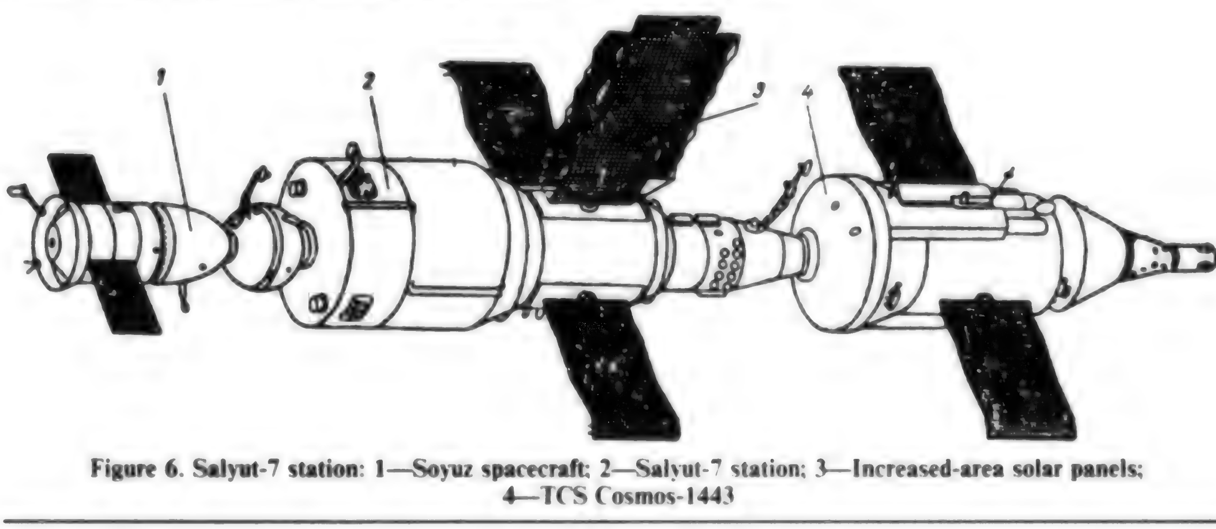


Figure 6. Salyut-7 station: 1—Soyuz spacecraft; 2—Salyut-7 station; 3—Increased-area solar panels; 4—TCS Cosmos-1443

As early as the initial stage of operations on the first-generation stations, it became clear that their capabilities were limited by their reserves of expendable components. Simultaneously, two OKBs—one headed by V. P. Mishin, the other, by Chelomey—got the idea of creating a station that would have two docking ports and whose propulsion system could be refueled in flight. The idea was brought to fruition in the second-generation stations—Salyut-6 and Salyut-7 (Fig. 6)—which were created by the Mashinostroyeniye Central Design Bureau branch No 1, which had become the independent Salyut Design Bureau.

The MCDB had prepared the Almaz-4 manned station for launch: it was equipped with a considerably improved complex of gear and had a longer lifespan and better characteristics. However, a delay of the Almaz program and its subsequent shutdown prevented the capabilities of the new vehicle from being realized. [If station had been launched successfully in 1979 or 1980, it would have received the name Salyut-7 or Salyut-8. It had two docking assemblies—one for receiving a TCS, the other for receiving Soyuz spacecraft.]

Chelomey proposed developing a heavy, improved [Almaz-type] orbital manned station with two docking assemblies. The most important distinguishing feature of that design was that a crew of four or five people would be able to leave the station together in a large return module at the forward end of the station. Continued operation of the station would be supported by launches of TSCs, which could dock at the station's two docking assemblies. To be able to lift such a station would require the development of a special launch vehicle capable of carrying 35 tons. The money for financing the design of a new launcher and the station, however, couldn't be found, and the work on the manned Almaz stations was shut down by 1978. In the USSR, only one program continued for the creation of manned stations. Involved in it were the NPO [scientific production association] Energiya, which had been EMCDB, and the Salyut Design Bureau. They created a third-generation orbital station, Mir, which was launched into orbit on 20 February 1986.

Despite the shutdown of its operations in the manned area, MCDB continued developing the Almaz station, but for unmanned operation. By abandoning systems associated with the presence of cosmonauts on the station, it was able to place a large complex of gear on the station for remote studies of the Earth, including a unique high-resolution side-looking radar. But the unmanned Almaz station, ready for launch in 1981, lay in one of the shops of the assembly-and-testing building at Baykonur until 1985. After perennial delays not associated with the work on that station, an attempt was made to launch the station. The attempt was unsuccessful, because of a failure in the control system of the Proton booster.

On 18 July 1987, there was a successful launch of an unmanned version of the Almaz station, under the name of Cosmos-1870. The high-quality radar images of the Earth's surface that were made by the vehicle were used in the interests of defense and the national economy of the USSR.

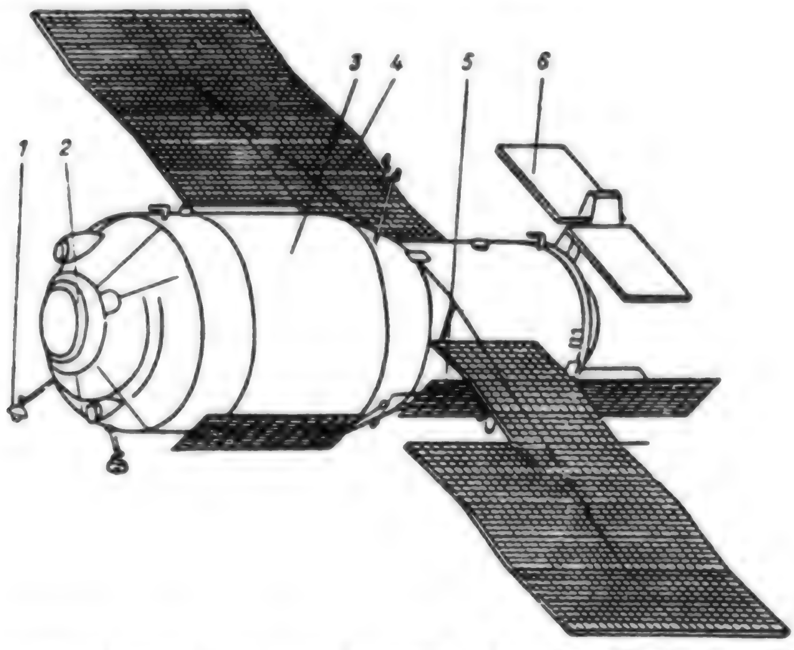


Figure 7. Almaz-1 unmanned station: 1—Antenna for sending information to Earth; 2—Additional fuel tank for propulsion system; 3—Modified version of Almaz manned station; 4—solar panels; 5—Side-looking radar; 6—Antenna for sending information via relay satellite

Finally, on 31 March 1991, an unmanned, modified version of the station that was developed by the MCDB and had considerably improved characteristics in terms of onboard gear was placed into orbit under its own actual name, Almaz-1 (Fig. 7).

Transport/Supply Craft (OKB-52)

For delivering crew and supplies to the Almaz manned station, OKB-52 developed a transport/supply craft (TSC) that consisted of a functional/cargo unit and a return module and was designed for launch by the UR500K rocket. An additional job performed by the TSC involved the use of its propulsion system and its electrical power-supply system in a long-duration joint flight with the station. The craft's control system would remain in reserve and would be switched on for controlling the flight of the station/craft linkup if need be.

A distinguishing feature of the return module was the presence of a transfer hatch in the thermal protection of the lower end, the most thermally stressed part of the craft.

Unlike the Soyuz spacecraft, where the reentry vehicle was located beneath the living/working section, the return module of the TCS was above, which ensured its reliable rescue in an emergency. Such a configuration required the presence of a hatch in the bottom of the return module for the transfer of the crew to the functional/cargo unit. That design initially raised doubts among many specialists (and still does), but subsequent full-scale launches of the return module confirmed the reliability of the design during reentry.

It should be noted that the return module inherited its configuration from its predecessors, which were developed in the LK1 and LK700 programs. Now one of the most important requirements made of the vehicle was that it be reusable. To effect that, the MCDB specialists developed a special-composition thermal protection that would not be destroyed during reentry.

The docking assembly of the TSC was located on the aft end of the functional/cargo unit in the area of increased diameter, in which the capsules for jettisoning information from the Almaz manned station would be located. Upon rendezvous with the station, the cosmonauts, in space suits, would be right next to the docking assembly and would observe the operations through a viewport. That simplified the docking procedure, expanded their view, and made it possible to abandon the system of periscopes and TV cameras that was used on the Soyuz spacecraft. In the event of impact during docking, the hull of the TSC could not depressurize quickly, because of the large internal space of the craft.

The docking assembly of the TSC had a design that was fundamentally different from the docking port of the Soyuz. It should also be added that, from the outset, the assembly was developed with an internal hatch/crawlway, whereas that idea was incorporated in the Soyuz craft much later.

The propulsion system assemblies, the fuel tanks, the attitude-control engines, and the solar panels were located around the hull of the TSC, outside the small-diameter area, and were enclosed in fairings during launch.

For testing the return module during reentry, OKB-52 created a special flight unit—a simplified TSC prototype consisting of a cylindrical adapter and two reentry vehicles, one secured to the upper part of the adapter, the other inside it, upside down. After injection into orbit, the reentry vehicles would separate and make separate reentries and landings. Mounted on the upper reentry vehicle was a solid-propellant emergency propulsion system, which on full-scale models of the craft served to remove the reentry vehicle, with the cosmonauts, from the booster in the event of a booster failure. A parachute system consisting of three parachutes and soft-landing engines was used for touchdown.

The first successful test of the prototype vehicle took place on 15 December 1976, when the UR500K booster placed the two satellites into orbit—Cosmos-881 and Cosmos-882. After one orbit, the reentry vehicles made a successful touchdown in the designated region of the Soviet Union.

The second launch of the flight unit took place on 30 March 1978. After a single orbit, the reentry vehicles, called Cosmos-997 and Cosmos-998, returned to Earth.

The third attempt at launching the prototype, on 5 January 1979, was unsuccessful because of a booster failure; the emergency rescue system successfully returned the upper reentry vehicle to Earth.

The last flight of the flight unit, which was launched on 23 May 1979 as Cosmos-1100 and Cosmos-1101, went much as did the previous flights, except that the upper reentry vehicle made two orbits. The vehicles made separate reentries 90 minutes apart.

The first launch of the fully outfitted TSC for structural and systems testing took place on 17 July 1977, under the name of Cosmos-929. A month later, the return module of the craft made a successful reentry and a successful landing in the designated area of the USSR. The autonomous flight of the functional/cargo unit lasted until 3 February 1978.

The second TSC, launched on 25 April 1981 under the name of Cosmos-1267, docked with Salyut-6 on 19 June. For compatibility of docking assemblies of the craft and the station, its last crew (V. V. Kovalenok and V. P. Savinykh), before returning to Earth, left the adapter in the cone of the docking port of the station, which ensured docking of the TSC without the closing of the locks of the assembly. In that mode, the TSC flew more than 400 days, corrected the orbit of the LOS, and, on 29 July 1982, after firing a braking impulse with its own propulsion system, went down with the station into the dense layers of the atmosphere and ended its existence. Before that, on 24 May 1981, the return module had been released from the TSC.

The third TSC, launched on 2 March 1983 under the name of Cosmos-1443, docked with Salyut-7 on 10 March. During that flight, the docking assemblies of both vehicles were modified so as to allow the station's crew of V. A. Lyakhov and A. P. Aleksandrov to unload the TSC while working in its interior compartments. On 14 August 1983, the TSC undocked from Salyut-7, and on 23 August, the return module made a reentry with the research results. The functional/cargo unit of "Cosmos-1443" continued until 19 September.

Although the UR500K Proton booster had been certified for use in manned flights as early as during the L1 Zond program, the presence of a large amount of toxic fuel components in its tanks raised some doubt as to the advisability of its use for launching manned TSC versions. As a result of a delay in the development of the supply craft and in connection with the broad startup of operations involving the Energiya/Buran system, the TSC program was shut down. The research base that was left was used in a program for the creation of cargo modules and scientific-technical modules for the Salyut-7 and Mir stations.

Boost-Glide Vehicle Projects (OKB-52)

Beginning in the early 1960s, while developing "spaceplanes" for manned flight to the planets, OKB-52 was conducting extensive research operations to determine the exterior of winged spacecraft for flights in artificial Earth satellite orbit and return to Earth. V. N. Chelomey headed the examination of various designs of such vehicles, called boost-glide vehicles. The area of application was identified for individual types of vehicles—including spacecraft with a low lift-drag ratio at hypersonic speeds; ballistic and semiballistic reentry vehicles; and vehicles with a mid-range ratio, like aerospace planes that make reentry in a thermally protected container and then, after passing through the segment of the highest heatup, jettison the container and make a gliding descent and a horizontal landing that involves the use of a swing-out wing and a turbojet engine. The greatest promise was held by the purely winged boost-glide vehicles, which enabled maneuvering in a broad range of speeds and directions. Such vehicles could make a controlled reentry with fairly small g-loads from any satellite orbit to a given point in the Soviet Union.

By 1964, at the Air Force's request, an experimental design of a single-seater boost-glide vehicle was created; it would be placed into near-Earth orbit by a Soyuz booster or a booster designed by OKB-52. Because the operations involving the Almaz complex were on the front burner by 1966, the development of the boost-glide vehicles was temporarily suspended.

After 1975, the work done by OKB-52 (Mashinostroyeniye Central Design Bureau) on winged spacecraft was resumed. Specifically, in 1979, an experimental design and a full-scale mockup were submitted for a lightweight space plane (LSP) that would be placed into orbit with the UR500K. Chelomey's OKB also proposed designs for LSPs that consisted of not only a reusable spacecraft, but also an expendable cargo section for delivering a heavy payload to orbit. Return of some of the cargo wold be done in the internal payload compartment of the spacecraft. That concept resembles the Western European design of the small orbital airplane, Hermes. Despite the fact that similar work was already being done abroad, the design appeared to the sector leadership to be too bold and too far ahead of its time, and it did not get any support. In 1981, the development of the LSP was shut down.

Reusable Vertical-Landing Transport Spacecraft Project (NPO Energiya)

In 1974, V. P. Mishin, who headed the EMCDB after the death of S. P. Korolev, was replaced by V. P. Glushko, who made the decision to abandon the development of the N1 rocket.

The shutdown of the N1 work came at a time when the American reusable Space Shuttle system was being developed. The U.S. Defense Department was not hiding the fact that the system could be used for military purposes. The Soviet military, striving to achieve strategic parity, ordered the rocket-space OKB to develop a reusable orbital craft with similar objectives, capabilities, and, consequently, specifications and performance characteristics.

Because of the lateness of the start, plans initially called for the creation of a system like the American system, consisting of a reusable winged orbiter with powerful oxygen-hydrogen LFREs, a large external tank containing fuel for the orbiter LFREs, and several reusable LFRE-equipped boosters, which would serve as the first stage. The mass and size of the proposed payloads dictated the size of the future orbiter and, of course, the characteristics of the system as a whole.

Academician Glushko, even before coming to the EMCDB, had studied a number of launchers formed from standard units collaterally joined. Each unit would carry a newly developed four-chamber oxygen-kerosene LFRE with a thrust of more than 700 tons-force, that LFRE embodying all the cutting-edge designs in the field of engine-building and the wealth of experience of the Gas Dynamic Laboratory/OKB. The launchers would also serve as the basis for the new concept of the Soviet rocket-space system.

The specialists who had been involved earlier in the development of Soyuz-type spacecraft saw that in addition to the obvious and well-known advantages, large winged orbiters also had substantial drawbacks. The principal drawbacks were the large mass of the wing and the fuselage, which would be covered with heavy thermal protection, and the need to build very long, high-quality, expensive runways for the horizontal landings of such systems. At the same time, the soft-landing parachute-deceleration systems widely used by the assault troops had demonstrated not only a high degree of reliability at low cost, but also acceptable characteristics in terms of accuracy of touchdown.

For that reason, in 1974, a wingless spacecraft was proposed. It consisted of a crew cabin in the forward, conical

part; a cylindrical cargo section in the middle part; and a conical aft section with a propulsion system for in-orbit maneuvering. After being launched by the heavy-lift booster and performing operations in orbit, the vehicle would enter the dense layers of the atmosphere and—using the small lift-drag ratio at hypersonic speeds of its lifting body, which had a cylindrical-conical shape and was equipped with air vanes and gas-jet vanes—perform a controlled descent with a given lateral range and a parachute-assisted landing on skis; the landing would use solid-propellant soft-landing engines in the final stage.

The most important difference between such a reusable, vertical-landing transport craft (RVTC) configuration and that of a winged orbiter like the Space Shuttle is that rather than being attached to the side of the booster, the former could be attached axially. The sustainer engines for the orbiter could be relocated from the vehicle itself to the lower part of the oxygen-hydrogen tank, and the entire system would be transformed into a classical launch vehicle, with collaterally arranged stages and the payload above.

Glushko was able to spot a grain of sense in that idea. Already the general designer of the new Energiya association, he commissioned the Voronezh OKB, Khimavtomatika, to develop the oxygen-hydrogen main LFRE. He understood that without the wealth of experience the Americans had in building engines that operated on cryogenic components entirely, we would be unable to quickly build a reusable LFRE with the necessary parameters. But with the payload above, we would be able to confine ourselves to developing an expendable oxygen-hydrogen LFRE. Moreover, expendable cargo containers of various sizes, meant for putting into orbit payloads of much larger mass than what could be carried in a reusable vehicle, could be mounted on the booster. In addition, the number of boosters that could be mounted around the main, second stage could be varied, from two to eight (a lateral placement of the spacecraft with payload would limit that number to a maximum of four).

With eight boosters and an enlarged second stage, the launch vehicle, which was given the name Vulkan, would be able to lift a 200-ton payload into orbit, which would make it possible to realize the idea that Glushko had been thinking about for so long—creating a spacecraft for a direct landing of a man on the Moon.

The opportunity, however, had been lost. The leadership was not earmarking any money for a lunar program even if it was in a new form. The top priority was to create a system like the American Space Shuttle.

By May 1976, a more detailed analysis of the configuration of the RVTC indicated the need to raise its hypersonic lift-drag ratio to increase its lateral range. The spacecraft (Fig. 8) acquired special triangular "bulges" that grew larger toward the tail and in which were located the soft-landing engines, the ski landing gear, and the air-vane actuators. As a result, the configuration of a winged spacecraft predominated, and the concept of an RVTC was abandoned in favor of Buran. The ideas underlying the design of the RVTC were used in the development of the system for recovering the strap-on boosters of the new launch vehicle, which was called Energiya.

Lunar Mission Spacecraft (NPO Energiya)

Appointed to head the newly formed NPO Energiya, V. P. Glushko, in October 1974, proposed his own comprehensive plan of operations for the association for the next few years. One point of the plan involved the creation of a long-duration research base on the Moon. Relying to some extent on the ideas of his predecessors, Glushko set up broader objectives than a short-term visit to the Moon. To achieve those objectives, preliminary

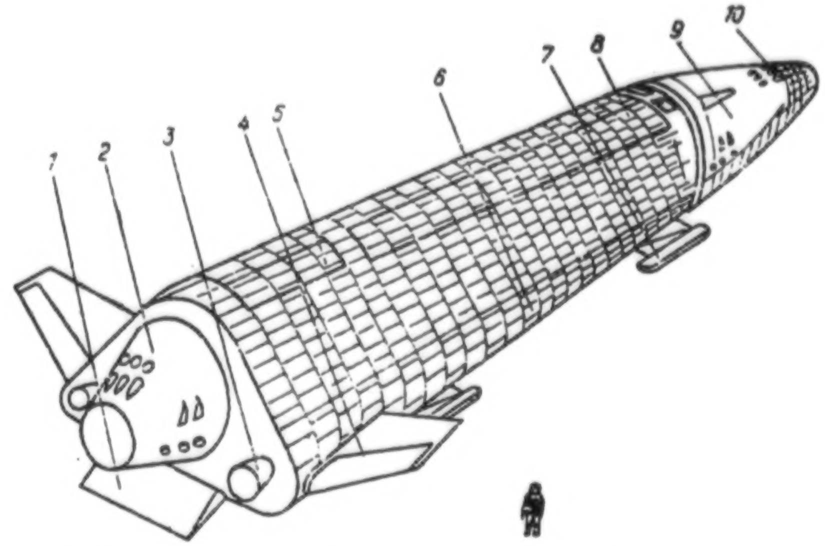


Figure 8. Reusable, vertical-landing transport craft: 1—Body flap; 2—Propulsion system and attitude-control system; 3—Propulsion-system LFRE; 4—Stabilizers with vanes; 5—Parachute compartment; 6—Lateral extensions; 7—Ski landing gear; 8—Payload compartment; 9—Crew cabin; 10—Nose LFREs of attitude-control system

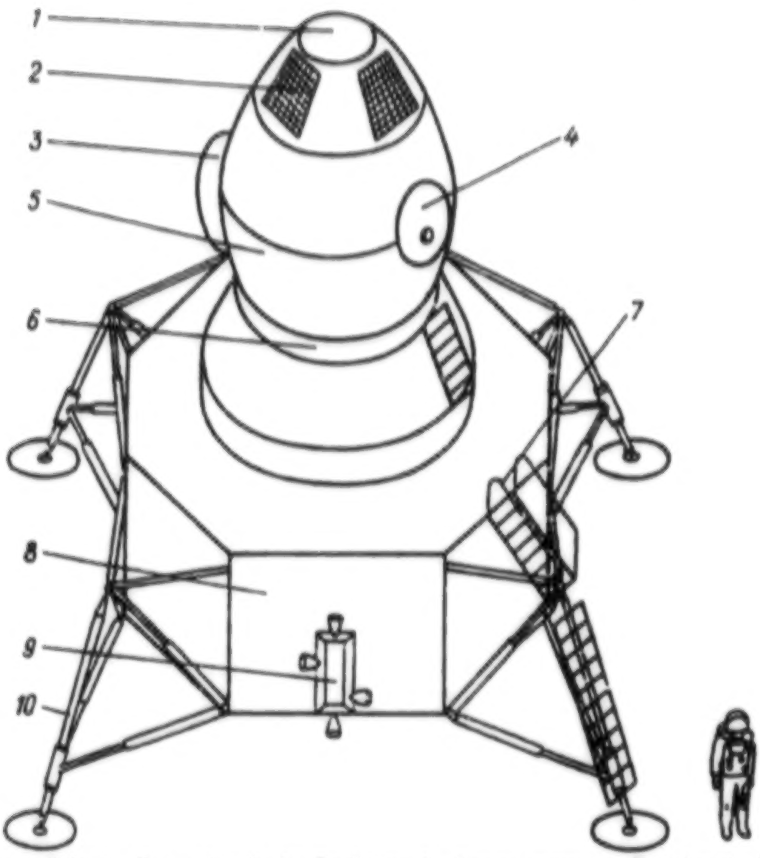


Figure 9. Lunar mission module: 1—Entry hatch; 2—Radiator; 3—Lunar rover; 4—Exit hatch; 5—Living quarters; 6—Ascent stage; 7—Ladder for exit to the lunar surface; 8—Landing stage; 9—Attitude-control LFRE unit; 10—Landing gear

design was initiated of new spacecraft for lunar missions, various versions of living complexes, and systems for getting about on the Moon.

The principal transport system proposed by Glushko for delivering cosmonauts and cargo [to the lunar surface] was the direct-landing lunar mission module (LMM) (Fig. 9), which was to be placed in translunar trajectory by a Vulkan booster with an oxygen-hydrogen upper stage.

The craft for the direct landing would have to consist of three main units: the landing stage, the ascent stage, and the living quarters. In its configuration, the landing stage—equipped with a powerful main LFRE and four steering LFREs—resembled the octagonal descent stage of the lunar module of the American Apollo craft. The ascent stage was nearly cylindrical. The unit that had been developed in the N1/L3 program would be used as the living quarters. Secured to the outside of that unit would be a large lunar rover for taking cosmonauts about the lunar surface. The electric power for the LMM in flight and on the Moon could be supplied by solar panels affixed to the upper part of the living quarters.

At launch, with the LMM in the upper part of the Vulkan booster, the spacecraft crew would be in the reentry vehicle, which would be secured inside the living quarters. On the whole, the flight of the LMM would resemble the mission proposed by the Mashinostroyeniye Central Design Bureau in the UR700-LK700 program. After the mission objectives were fulfilled, the portion of the LMM to return to Earth would be lifted off by the ascent stage. Before reentry, the reentry vehicle would separate from the living quarters.

The country's leadership felt no enthusiasm whatsoever for the "new" lunar program and was in no hurry to earmark money for Glushko's plans. At the same time, the goal that had been placed before our space program to develop a reusable orbiter pushed the work in the lunar area into the background. Setting up a base on the Moon with new equipment would require huge amounts of money, amounts that exceeded considerably the spending in the H1/L3 program. When the new lunar program and the program for developing a universal space transport system were juxtaposed with the reusable orbiter, the orbiter was given priority. Glushko, to the

very last days of his life, tried to rouse interest in the plans for exploring the Moon, but he never succeeded in convincing the "higher-ups" of the need to finance the program.

Zarya Spacecraft Project (NPO Energiya)

In addition to the spacecraft based on the Soyuz craft (the manned Soyuz-T and -TM, as well as the unmanned Progress and Progress-M), the specialists at NPO Energiya often proposed designs of various vehicles that were meant for boosters that were more powerful than Korolev's "No. 7," but were less expensive than the Buran orbiter. One of them was a design for the Zarya transport craft, which would be launched into orbit by the Zenit booster. The work on that spacecraft went on in the second half of the 1980s.

The main task facing the designers was to create a multi-seater, reusable transport/supply craft. To accelerate the work on the project, all the experience garnered by the NPO in previous work on manned and unmanned space hardware was to be used. After analysis of various component configurations, it was decided to develop a spacecraft in the form of a large reentry vehicle that would have a small lift-drag ratio and would make a vertical landing.

Initially, the Zarya developers intended to design a fully reusable vehicle that would not contain any expendable elements to be jettisoned in flight. All the onboard systems would be located inside the craft, which would be shaped like a Soyuz reentry vehicle, but with a diameter at the base of approximately 3.7 m. Such a spacecraft, weighing nearly 13 tons, could deliver a payload of more than 1.5 tons to the station in the manned version and roughly two and a half times that in the unmanned version.

Zarya was to have an androgenous-peripheral docking assembly in the upper part of the craft, a five- or six-seater crew cabin in the central part, and a cargo section in the lower part. All the service systems and assemblies of the vehicle would need to be compactly located between the walls of the cabin and beneath the thermal protection shield. Various antennas would be mounted on the interior covers of the hatches that opened into space.

As a result, however, because of the lack of space in the reentry vehicle, the designers introduced a fairly small equipment section with a propulsion system for orbital maneuvering and a thermal-regulation system radiator in the lower part of the spacecraft. The equipment section would be jettisoned just before reentry, after the braking impulse had been completed.

The main difference between the Zarya and the earlier examined vehicles was the interesting profile for its landing system. After the aerodynamic braking leg and after release of the stabilizing parachute and landing gear upon command from the radio altimeter, a landing parachute system would not deploy; instead, at a very low altitude, several seconds before touchdown, a large number of LFREs mounted on a ring around the reentry vehicle airframe would fire and would decelerate the fall of the vehicle to a velocity of almost zero. In addition to the function of braking the vehicle during landing, those LFREs also performed the role of engines for attitude control and docking in space. The nozzles of the engines pointed out at an angle from the axis of the spacecraft so that their streams did not damage the skin of the spacecraft. Since the fuel for those engines would also be located inside the reentry vehicle, the LFREs would have to burn nontoxic components.

A similar system for deorbiting—one that used the experience of the soft lunar landing of the Apollo space vehicles for large vehicles such as single-stage launch vehicles—was proposed in the 1960s by the English specialists F. Bono and K. Gatlend. The main LFREs of the rocket, which burned the residues of fuel (hydrogen and oxygen) from the booster tanks were to be used as the landing engines.

Using its fairly low lift-drag ratio, Zarya could select the area of the Earth needed for the landing, which meant there wasn't any need to build special landing fields. The g-loads on all the segments of the vehicle's flight had acceptable values.

In addition to the advantages associated with its reusability, the Zarya design had several drawbacks, one being the high level of acoustic loads on the crew during landing—the braking LFREs were located right next to the cosmonauts. Also eliciting some doubt was that fact that the spacecraft's concept did not provide for the possibility of using the atmosphere for landing.

Because of the budgetary difficulties that faced the space program in the late 1980s, as well as the busy schedule the NPO had as a result of the Energiya/Buran system and other programs, the Zarya design was developed no further.

Conclusion

You have now been familiarized with some of the spacecraft designs that were under development in the Soviet Union in the 1960s, 1970s, and 1980s. Of course, it would be impossible to go into detail on every one of them. But even the list that's been presented here is clearly enough to let the reader see that the Soviet space program during all those years was a huge iceberg, only the small tip of which was accessible to the gaze of the outside observer.

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